



GROUNDWATER POTENTIAL ASSESSMENT USING GIS AND REMOTE SENSING: A
CASE STUDY IN MANTHA WATERSHED, OMO-GIBE RIVER BASIN, ETHIOPIA.

MSc. THESIS

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CASE STUDY IN MANTHA WATERSHED, OMO-GIBE RIVER BASIN, ETHIOPIA.

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DECLARATION

I hereby declare that this MSc thesis is my own work, and all sources of material used for this thesis have been duly acknowledged.

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Abbreviations and Acronyms

AHP	Analytical Hierarchy Process
BCM	Billion Cubic Meter
CR	Consistency Ratio
DEM	Digital Elevation Model
DD	Drainage Density
EGS	Ethiopian Geological Survey
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GWPZ	Groundwater Potential Zone
IDW	Inverse Distance Weight
KM	Kilo Meter
KM ²	Square Kilometer
LULC	Land use land cover
MCDM	Multicriteria Decision Making
NMA	National Meteorological Agency
OLI	Operational Land Imagery
RS	Remote Sensing
SRTM	Shuttle Radar Topography Mission

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ABSTRACT

*In the current study area, the demand for groundwater is increasing. Therefore, the ultimate purpose of this study was to map groundwater potential zones in Mantha watershed using geographic information system and remote sensing. Ten groundwater controlling factors (geology, rainfall, lineament, soil, land use/land cover, geomorphology, slope, and distance to river, elevation, and drainage density) were used to map the groundwater potential zones of the study watershed using remote sensing data. Among these, three layers (geology, geomorphology, and soil) of the study watershed were extracted from existing data, and five layers (slope, drainage density, elevation, lineament, and distance to river) were developed using DEM of 30m*30m spatial resolution. 20 years precipitation data obtained from National meteorology Agency of Ethiopia were converted into areal rainfall using inverse distance weight interpolation method integrated with ArcGIS 10.8 to develop rainfall layer of the study watershed. Landsat8 of the year 2020 was used to map the land use/land cover of the study watershed using supervised image classification with maximum likelihood algorithm in ERDAS 2015. Then, all thematic layers were reclassified using literatures and Jenks methods and finally rated in analytical hierarchy process.*

The results of ten thematic layers data rated in in analytical hierarchy process indicated that the most dominant thematic layers that hold high weight relative to others were- geology (28%), rainfall (16.6%), lineament density (12.9%), and soil (10.3%). Groundwater potential map of the study watershed was obtained by using weights derived from AHP and overlay analysis conducted in arc GIS10.8_ platform. There were four groundwater potential zones mapped in the Mantha watershed, namely, very high, high, moderate, and low.

The map result was verified by well data and the result showed strong agreement in each category with 85.7%, 83.33%, 90%, and 100% respectively. The finding of this study indicates that the geographic information system and remote sensing model approach are reliable and can be a reliable prospecting method of groundwater potential zone.

Key words: Geographic information system, Remote Sensing, Groundwater potential zone, Analytical hierarchy process, Mantha Watershed, Overlay analysis

1. INTRODUCTION

1.1. Background

Groundwater is the most abundant source of fresh water on earth. It is a resource hidden in the pores and cracks underground, after percolating from the Earth's surface (Fitts, 2012), (Berhanu et al, 2014). Therefore, water found underground in the cracks and spaces in soil, sand, and rock is called groundwater.

Groundwater is a valuable and important natural resource used for drinking water supply, livestock, irrigation, hydro-power development, industries, and domestic purposes in the world (Rahmati and Melesse , 2016). Due to increased demand for groundwater continues, the need for evaluating of groundwater potential zones becomes essential for conducting groundwater protection, and management schemes (Naghibi and Pourghasemi , 2015).

The availability, and occurrence of ground water depend on factors such as geology, slope aspect, lineaments, drainage density, elevation, land- use/land-cover, Rainfall, geology, distance to river, and geomorphology of the area (Shaban et al, 2005).

The factors determining groundwater potential could be studied through the application of Geographical information system (GIS) and remote sensing (RS) methods (Kamal, 2017). GIS and RS can efficiently deal with spatiotemporal data. GIS offers the platform to handle the extensive dataset capably, whereas RS provides quick access to the information (Patra et al, 2018). Groundwater water resource was effectively analyzed and predicted using Remote sensing application (El, 2017); (Gebremichael et al, 2018).The ability of satellite imagery to cover large spatial scales is necessary for the depiction of basins physiographic characteristics, such as land use/land cover, slope, and drainage density as well as structural characteristics such as fractures, faults, and cleavages (Kuria et al, 2012); (Sree et al, 2001). Beside to geographic information system and remote sensing, Multicriteria analysis using AHP can provide efficient method for studying groundwater resources. Various researchers have applied AHP with GIS and RS based study on groundwater availability (Adiat et al, 2012); (Arulbalaj, 2019); (Das & Pardeshi, 2018); (Machiwa et al, 2011); (Mohammadi-Behzad et al, 2017); (Shekhar & Pandey, 2014); (Thapa et al, 2017) with GIS and remote sensing techniques in their study areas watershed.

Several decision analysis approaches such as Multi-criteria Decision Making (MCDM), and Analytical Hierarchy process (AHP) are also additional options to perform suitability analysis. MCDA techniques were used by (Jennifer et al, 2017) for studying groundwater availability, and evaluation. Moreover, GIS-based multi-criteria analysis is also useful in evaluating and identifying groundwater availability as reported by (Singh et al, 2017) : (Althuwaynee et al, 2014). In most research papers, the model AHP is integrated with remote sensing and geographic information system techniques for the assessment and identification of GWPZs in different study areas have been conducted by allocating weights to the different parameters and their feature classes using the AHP methods (Mallick et al, 2019).

Therefore, considering different case studies, a set of factors believed to be influencing groundwater potential in the present study watershed were selected. Each criterion/factor was assigned appropriate weight based on Saaty's 9 point scale and the weights were normalized through the analytic hierarchy process (AHP). An AHP technique was involved to perform the comparative weight assignment for selective influential parameters (geology, rainfall, lineament density, drainage density, geomorphology, slope, distance to river, elevation, LULC and soil) on the given Saaty's scale by setting objectives of such issues were achieved (Saaty and Varga, 2001). Therefore, thematic maps and their features were assessed weight to relative importance of them to develop groundwater potentiality in current study watershed. The set of objective features were involved in decision making process. Then after assigning appropriate weights considered in AHP to overcome with overlay analysis using GIS, the resulting map was identified show potential zones (very high, high, moderate, and low potential) of present study watershed. Therefore, the present study watershed was focused on the groundwater potential assessment in Mantha watershed, Omo river basin using GIS and remote sensing.

1.2. Statement of the Problems

Groundwater utilization without knowing its availability through identifying potential zones is becoming key problems. The problem is common in developing country like Ethiopia. Lack of spatial information on distribution of ground water resource is poorly understood during groundwater exploration (Tesfaye, 2012). Groundwater potential zone was mapped using geographic information system and remote sensing in time and cost effective manner as

studied by (Davoodi et al, 2015): (Gha et al, 2010). In the current study area, the number of population increases from time to time and most of them use water for potable drinking and irrigation from Mantha watershed and its tributaries. Many efforts have been made by various governmental organizations to make water available in the area through drilling of boreholes, and water point development in addition to hand dug wells. Selection of potential zones for groundwater supply relies heavily on traditional field methods using known water yielding sites as guidelines. Lacking systematic approach to groundwater exploration is the main problems in and around in the study watershed.

There was no previous study conducted in the current study watershed regarding groundwater potential mapping. The present study was solved the problems by applying GIS and Remote sensing by mapping the ground water potential zones. Therefore, the result of this research was encouraged by mapping results obtained during study period using remote sensing and geographic information system techniques. The finding of this study would reduce problems related with groundwater exploration by mapped the best site of study watershed to develop groundwater.

1.3. Objective

1.3.1. General objective

The main objective of this study was mapping the groundwater potential zones using GIS and Remote sensing techniques in Mantha Watershed, Omo-Gibe River basin, Ethiopia.

1.3.2. Specific objectives

- To develop the thematic layers of the study watershed considering factor affecting groundwater.
- To identify the most influencing factors in identifying groundwater potential zones.
- To verify the resultant potential map using well data.

1.4. Research Questions

- ✚ What are the characteristics of thematic layers used for this study watershed?
- ✚ Which zone is low or high potential of groundwater in the study watershed?
- ✚ Is th identified groundwater potential map is accurate?

1.5. Significance of the Study

The prepared groundwater potential map may also use as Geo database which will permits decision makers sustainable use of present and future groundwater resources. In addition to this groundwater potential zone map may provide information about groundwater potential sites in the study watershed. This could reduce the extra labor and time required in-sitting well location for ground water exploitation. The assessed and documented current groundwater condition (groundwater potentiality), and associated controlling factors must be identified to address the future increase in groundwater demand. Understanding the amount of groundwater resources and creating awareness among decision makers to use, manage, and to protect groundwater without adversely affecting its future demand. Therefore this paper will be used as reference for the next researcher to improve hydrogeological understanding of the Mantha watershed and it is best regard understanding groundwater potential of the study watershed is useful to regulate and optimize water use without impacting water resources for the future use.

2. REVIEW OF LITERATURE

2.1. Groundwater Resources and its Occurrences

According to (Freeze and Cherry, 1979), groundwater is the subsurface water that occurs beneath water table in the soils and geologic formations that are fully saturated. Researchers have investigated how and when groundwater occurred. Based on their investigation, when rain falls to the ground some degree of it flows along the land surface to rivers, lakes, streams, the other moisturizes the ground. Part of this water also seeps into the ground, flows through the unsaturated zone, and reaches the water table; the last one is groundwater which found beneath the ground surface in the saturated zone. According to (Lehr et al, 2005), it is a water stored in the open spaces and fractures within geologic formations beneath the sub surface known as aquifers. An aquifer is a geological formation or part of it, consisting of permeable material capable to store or yield significant quantities of water (Freeze and Cherry, 1979) :(Lehr et al, 2005).

Groundwater is a major source of water supply and food production on irrigated agriculture worldwide. It plays an important role in sustaining rivers, lakes, and wetlands during dry periods and is also essential for many ecosystems (Adem and Batelaan , 2006).

Groundwater comprises 99% of the earth's available fresh water resources from total groundwater of the world estimated to be 10.53 Million km³ (Delleur J. , 1998). It is less contaminated by wastes and can sustain the flow of surface water during dry periods. Ethiopia is considered as a water tower of Africa next to Zaire, due its plenty of water resources available on the surface and groundwater beyond the erratic rainfall. Other authors, (Pavelic et al, 2012) investigated on groundwater potential and use in the sub-Sahara African country review. He concluded that the Hydrological conditions of sub-Sahara Africa are the major controller of under groundwater more than other country and categorizes the hydro-logical aquifers parameters of sub-Saharan into crystalline basement complex rock, consolidated sedimentary rock, unconsolidated sedimentary rock, and volcanic rocks.

According to (Kebede et al, 2013) the total groundwater storage potential in Ethiopia is estimated to be 2.6 to 6.5 billion m³ but, this was extremely underestimated indicated by (Awulachew et al, 2007). The condition of groundwater occurrence in Ethiopia and possible factors governing groundwater flow were described by (Tamiru A. , 2006). Not only this but also, he generalized the variation in mineralogy, texture, and structure of volcanic rocks cause the variation of water bearing capacity of the area. Based on the source of groundwater recharge options in country, (Seifu Kebede, 2012), conducted partly on groundwater occurrence in Ethiopia and evident of water isotope was summarized. Distribution of lithology in Ethiopia was categorized as sedimentary and Mesozoic sandstone to the Southern, Karstic rocks to eastern and southeastern, quaternary volcanic rocks and unconsolidated sediments in rift valley and low land depression area, fractured intrusive rocks, old Precambrian rocks and metamorphic rocks to western part of Ethiopia and their aquifer characteristics (Tamiru A. , 2006). Therefore, this is a scientific fact why the geological environment must be assessed to know potential area suitability for groundwater occurrence and which zone should be protection zone in order to meet future water demand. Thus, zones of abundant groundwater available for use and productive water bearing zones should be correctly sited to get sufficient quantities. It needs to have a very detailed study on this issue so that enough information is available.

2.2. Factors Determining the Occurrence of Groundwater

2.2.1. Slope

Slope is an important factor which determines groundwater potential zones, high degree of the slope results high runoff and increases erosion rates which decreases infiltration rates (Magesh et al, 2012). It is one of the factors controlling infiltration of water to the ground and the indicator of groundwater potential suitability (Yeh et al, 2016). Areas with gentle slopes caused less runoff, high infiltration and have high groundwater prospects compared to the areas with steep slope. Gentle slope areas caused less runoff, high infiltration rate and have good groundwater prospects. Researchers were agreed that slope is a good proxy for groundwater potential assessment. Their finding demonstrates that slope highly influences groundwater infiltration and recharge. Groundwater potential is low where in the area of steep slopes present, because there is less infiltration than surface runoff (Yeh et al, 2016). Based on

this, area characterized by flatland groundwater potential was discovered to be high because it is easier for the water to form pools and infiltrate than to runoff on the surface.

2.2.2. Rainfall

Groundwater recharged from rainfall (M. Stute et al, 2007) and amount of water that would be available to percolate into the groundwater system is determined by rainfall. It is an important hydro-logic element (Adiat et al, 2012) and high rainfall is favorable for high groundwater potential. Therefore, any changes in the rainfall quantity and storm pattern can affect the recharge quantity since it has direct impact on the rate of infiltration; this is the reason why rainfall is the main recharge of groundwater reservoirs. Due to this, during the weighting it is assigned a higher priority.

2.2.3. Geomorphology

Based on the geomorphology point of view, the characterization and identification of various landform and structural features are very important. It determine groundwater potential and recharge zone (Shifaji. and , Nitin, 2014), subsurface movement of groundwater controlled by it and important features in evaluating the groundwater potential and prospect. Have geological utilization to manage of groundwater resources (Valliammai et al, 2013).Therefore, classifying geomorphology in terms of groundwater recharge and potential the geomorphology of the study area classified in to a certain unity would decide availability of groundwater in the current study area.

2.2.4. Drainage density

Drainage density is used to represent the drainage of the watershed which is the total length of the stream and its tributaries over the total area of the drainage watershed (Greenbaum, 1989). The higher drainage density, steeper slope with low permeability thus less infiltration and more surface runoff. When the drainage density of an area is low, it is indicative of low runoff and results high infiltration rate whereas high drainage density in an area implies high runoff and low infiltration (Patra et al, 2018). Therefore, high drainage density increases surface runoff and decreases infiltration. This indicates how the drainage density influences the suitability for groundwater recharge of an area due to its linkage with surface runoff and permeability.

2.2.5. Land use land cover

The amount of water that contributed to groundwater recharge through infiltration process depends on land use/cover types. The land use/land cover type can either increase or decrease infiltration rate, this is the reason why bare areas are least suitable land cover for infiltration, while vegetated surfaces are highly rated for reducing runoff and facilitating infiltration (Nagarajan . and Singh, 2009).

According to (Leduce et al, 2001), classifying land use land cover becomes important indication of high groundwater potential and vegetation plays a great role for groundwater recharge. This is related to hydrological processes such as infiltration and groundwater recharges also affect when land use land cover changes occur (Lin et al, 2007). Several literatures showed how land use land covers influencing groundwater occurrence, groundwater recharge and availability (Hussein et al, 2016); (Kumar et al, 2016); (Pande et al, 2017); (Yeh et al, 2016).

2.2.6. Lineament distributions

Geological structures such as (fault and fractures that have no significant fracture displacement) are manifested at the earth's surface of deeper (Han et al, 2018). To investigate the distribution of potential areas for runoff water harvesting were determined by it and also the regional distribution of groundwater potential sites have been determined (Magesh et al, 2012).

2.2.7. Soils

Soil characteristics are factors that controlling the water holding capacity and important prospects in delineating groundwater potential (Anbarasu et al, 2019). Moreover, it has a significant control on the infiltration and percolation rates into an aquifer (Anbarasu et al, 2019).

2.2.8. Elevation

The movement and infiltration of groundwater are determined by topographic nature of certain watershed. Infiltration may store in lower topography than higher topography and groundwater movement is also from higher topography to lower topography (Shifaji. and , Nitin, 2014).

Therefore, topographic variation in study watershed can create possible variation in groundwater storage and distributions of groundwater resources having varied characteristics of it.

2.2.9. Geology

(Chowdhury et al , 2010), have explained that different lithological units are very important aspect in evaluation of groundwater potential zones. They also verified that higher porosity of lithological units contributes to higher permeability, which in turn contributes to create higher potential to produce higher groundwater yields in a certain study catchments. Due to this it should include in this study to characterize its relationship with groundwater potential formation according to study watershed hydrogeology.

2.2.10. Distance to river

Zones near to rivers are contributes effective infiltration facilitates good groundwater potential formation (Moghaddam et al, 2015). This indicates that different aquifers found near to rivers increases rate of groundwater recharge than located away from different rivers. Therefore, based on the above reviews it should be observed from recommended distance supported by the above literatures in study analysis.

2.3. Role of GIS and RS in the Determination of Groundwater Potential zones

The geographic information system offers spatial data management and analysis tools that can assist users in organizing, storing, editing, analyzing, and displaying positional and attribute information about geographical data (Burrough, 1986).

A cost and time effective means of assessing and managing groundwater resources by using integrated remote sensing and geographic information system approach were applied by several researchers (Jha et al, 2007); (Meijerink, 2007). Now a day, techniques are being used to integrate various data to solve problems related to delineating groundwater potential zones. Various data are prepared in the form of a thematic map using GIS software tools and these thematic maps are then integrated using “Spatial Analyst” tool. According to (Adiat et al, 2012), hydrogeological significance can be extracted from remote sensing data. (Pothiraj & Rajagopalan , 2012), have explained about analysis of remotely sensed data for groundwater

controlling factors (drainage, geology, geomorphology, and lineament, LULC...etc.) characteristics of the terrain are an integrated way facilitates evaluation of groundwater potential zones.

Generation of thematic maps is very important for the assessment of groundwater potential zones in a given study watershed. By using geospatial technologies, it is possible to map groundwater potential zones (Kuria et al, 2012). The utility of geospatial technologies in estimating the groundwater potential was demonstrated and the study found out that the most suitable areas for groundwater prospecting were mapped. (Ganapuram et al , 2008), also have mapped groundwater potential zones in the Musi basin, India using Remote Sensing data and GIS. They delineated prospective zones of groundwater in the basin. Most of the researchers have used remote sensing and GIS for demarcating groundwater potential areas in the different regions (Krishnamurthy et al, 1996). They prepared the maps of Lithology, landforms, lineaments and surface water bodies, drainage density and slope. These thematic maps were integrated and analyzed using a GIS based model developed with logical conditions in a GIS environment. Finally, the groundwater potential zone map thus developed was verified with borehole well logs, which indicated a good agreement.

2.4. Analytical Hierarchy Process (AHP)

It was introduced by Saaty in 1970s (Saaty and Varga, 2001) and a technique has been used for multi-criteria decision making approach. Due to the nice mathematical properties of the method and the fact that the required input data are rather easy to obtain, many researchers interested on it. The AHP is a decision support tool which can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub criteria, and alternatives. The data are derived by using a set of pair wise comparisons. These comparisons are used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion (Kousalya et al, 2012).

3. MATERIAL AND METHODS

3.1. Description of the Study Watershed

3.1.1. Location and size of the study watershed

This study was conducted in Mantha Watershed which, is found in Dawro Zone, South Western Regional State of Ethiopia. The watershed touches seven administrative districts of Dawro Zone: Loma, Disa, Mareka, Mari-Mansa, Tocha, Kach, and Esara. Geographically, the study watershed is located between 6°38'0" to 7°6'30" Northing and 36°50'30" to 37°16'0" Easting. The watershed is originated from Shepa spring located in highland area of Tocha Districts flowing toward Mari-Mansa area and joins other watersheds draining from Mareka and Loma districts between lowland area of Esera and Loma; finally its outlet is drains toward Disa lowland area then enter into Omo river basin. Mantha watershed is one of the main perennial rivers and longest watershed of other watersheds draining from Dawro Zone to Omo river basin and it covers total surface area of 1215.64 km². The elevation of the study watershed ranges between 2798 meters above sea level in upper part of Tocha Tuta highland and 600m.a.s.l in lower part of Disa lowland.

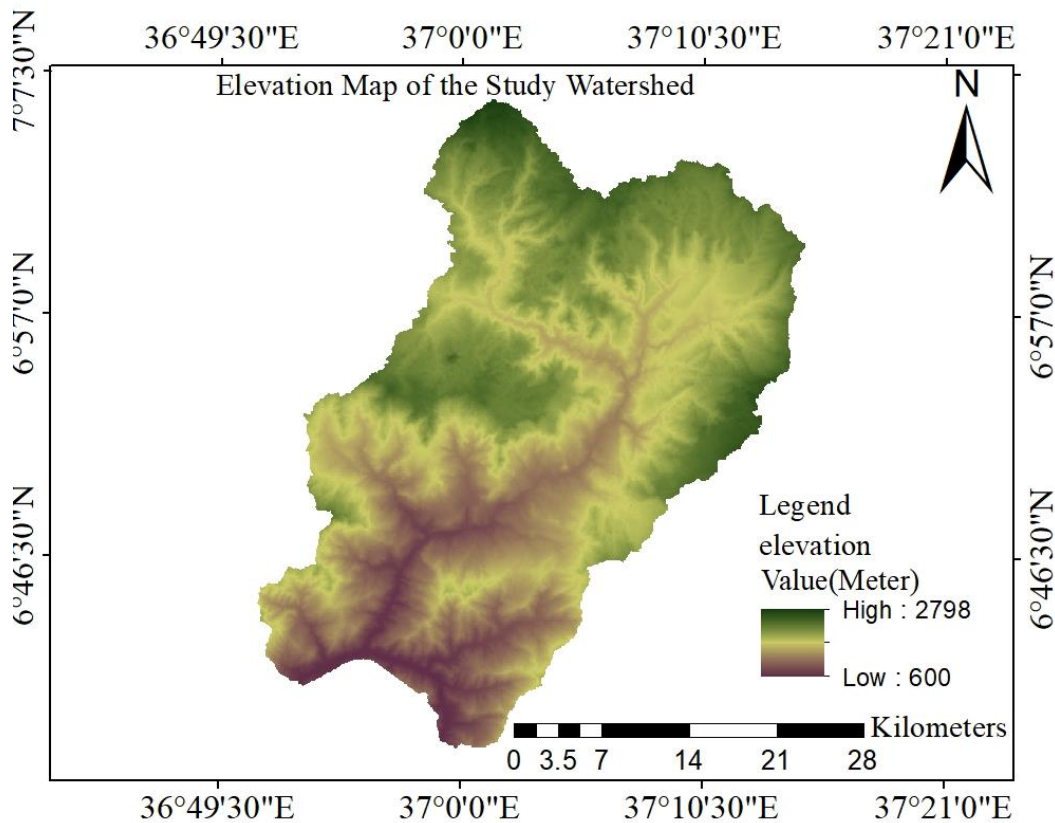


Figure 3-1: Elevation Map of the Study Watershed

3.1.2. LULC of the study watershed

In this study, Landsat8 (OLI) of the year 2020 was used to map the land use/land cover of the study watershed using supervised image classification with maximum likelihood algorithm in ERDAS 2015_ platform.

3.1.3. Agro-ecology and climate of the study watershed

Agro-ecologically, according to the traditional classification of agro-ecology of Ethiopia, study area is classified into three agro-ecological zones. Elevation range greater than 2300m as highland, lies between 1500 to 2300m midland (Woina dega), and below 1500m lowland (kola) ministry of agriculture (MoA), 2000).

There are six meteorological stations in and around study watershed. Based on the data obtained from National Meteorological Agency the analyses of data shows that the study watershed receives an average annual rainfall of 1437.574 to 2062.856mm. The results of

analyses also show that the rainfall pattern in the study watershed is bimodal, that is because Ethiopia is situated under the influence of Inter Tropical Convergence Zone. When the Inter Tropical Convergence Zone just moves from South to North the small "Belg" (March-April) rains prevail (be happening) in the study watershed. When the Inter Tropical Convergence Zone is beyond the Northern boundary heavy "Kiremt" rains prevail. Its long term annual temperature of the study watershed varying from 15.1 °C and 27.5 °C (MoA), 2000).

3.2. Data Collection and Analyses

3.2.1. Development of thematic layers of the study watershed

The study watershed was delineated from DEM images using GIS10.8_platform. Groundwater controlling factors considered in study watershed (geology, rainfall, lineament density, soil, LULC, geomorphology, slop, drainage density, elevation, and distance to river) were developed from various data. Thematic layers were developed by considering criteria used for groundwater potential assessment, and details of the development of the thematic layers are given as follows.

3.2.1.1. Rainfall thematic layer of the study watershed

Rainfall is a significant parameter during groundwater potential assessment. The amount of rainfall varies from place to places and it is also varies based hydro- meteorological conditions of the certain place. This indicates that the possibility of groundwater is low if the place where rainfall is low and it is high if rainfall is high (Ramu Mahalingam, B., and Vinay, M. , 2010). Rainfall also varies temporally, and hence, to determine the influence of rainfall in any region requires long term climatological study.

There are six meteorological stations in and around study watershed. From these stations, only four stations were selected for the preparation of areal rainfall of the study watershed. The other two meteorological stations (Tocha and Gena Bossa) were left due to lack of long term rainfall record. Instead, they were used to fill the missing data of the other meteorological stations (Tarcha, Gessa Chare, Dedo, and Chida) of the study watershed. Normal ratio method was found to be appropriate technique to fill missing data and thus, it was applied for this matter. As per the normal ratio method, the missing precipitation was estimated as

$$P_X = \frac{1}{N} \sum_{i=1}^{i=n} \left(\frac{N_X}{N_i} * P_i \right) \dots\dots\dots (3.1)$$

Where,

P_X is the missing precipitation for any storm at the interpolation station ‘x’; P_i is the precipitation for the same period for the same storm at the "ith" station of a group of index stations, N_X the normal annual precipitation value for the 'x' station and N_i the normal annual precipitation.

In this study, IDW interpolation techniques integrated with GIS was used to estimate the areal rainfall distribution in the study watershed. Rainfall data was obtained from the National Meteorological Agency of Ethiopia. Rainfall distribution layer of the study watershed was developed by converting measured point data to areal rainfall using ID interpolation techniques in ArcGIS 10.8_platform and Jenks classification method (GF, 1967) was used to classify areal rainfall distribution of the study watershed.

3.2.1.2. Slope thematic layer of the study watershed

According to (Chenini, and Mammou, 2010), high slope regions have high runoff and low infiltration rate, and, thus, not suitable for groundwater recharge, because of water cannot get enough time to infiltrate to the ground. Slope is an important factor which determines groundwater potential zones, high degree of the slope results high runoff and increases erosion rates which decreases infiltration rates (Magesh et al, 2012). It is one of a factor controlling infiltration of water to the ground and the indicator of groundwater potential suitability (Yeh et al, 2016).

The slope of the study watershed was extracted from SRTM DEM which is 30m*30m resolution using ArcGIS10.8_platform. FAO slope classification method was used to classify the slope distribution of the study watershed. Topographic attributes of elevation also were derived from SRTM DEM 30m *30m and Jenks method (GF, 1967) was used to classify to verify each slope class.

3.2.1.3. Drainage density thematic layer of the study watershed

Based on (Yeh et al, 2009), drainage density defines the potential of the groundwater recharge area. According to study conducted by (Murthy, and R. Pradesh, 2000); (Kumar, and Krishna, 2018), low drainage density indicating high potential for groundwater recharge.

To develop drainage density layer of the study watershed, initially a filling sink was performed from SRTM Digital Elevation Model (DEM) 30m* 30m spatial resolution using ArcGIS 10.8_platform. Then a flow direction map was generated from the fill sink applying the flow direction tool. A flow accumulation map was generated from the flow direction by applying the flow accumulation tools in Arc Hydro tools. The stream definition map was made from the flow accumulation parameter applying the raster calculator tool of the map algebra tool. Stream network was created applying raster calculator tool after delineating all surface parameters. Finally, drainage density layer was developed by applying the line density tool of the spatial analysis tools in ArcGIS 10.8_platform. The drainage density was calculated from the total stream's length of the study watershed per unit area using Equation 3.2. The approach followed by (Allafta et al, 2021) was used classify drainage densities.

$$Dd = \sum_{i=1}^n (L/A) \dots\dots\dots (3.2)$$

Where,

Dd = Drainage density (km/km²),

L, Total length of streams (km)

A = Surface area of the watershed (km²)

3.2.1.4. Lineament density thematic layer of the study watershed

Most of the geological linear features are assumed to be the zone of fractured bed rocks and the position of porous and permeable state where enhanced well yields can be expected (Meijerink, 2007). According to (Devi et al, 2001), fractures facilitate infiltration of surface runoff into the subsurface and are of great relevance to the storage. Therefore a high lineament density value refers high secondary_porosity, thus indicating a zone with high levels

of groundwater recharge. This means that lineament density map can indirectly reveal the groundwater potentials as the presence of lineaments usually denotes a permeable zone. Structural features play important roles in groundwater exploration. Because of this, their mapping may help geologists in locating areas of possible high groundwater zone.

SRTM DEM image was used to derive hill shade images using ArcGIS 10.8 Spatial Analyst tools. Four azimuth values were applied to the SRTM DEM image, namely: 315°, 220°, 150° and 100°. Several linear structures were identified from the hill shade images after hill shade processing of the images. Then for validation, non-geological linear features such as roads and others that do not correspond to geological structures are identified from produced geological map of Ethiopia by displaying study watershed boundary. Lineament density layer was generated by using line density tool of ArcGIS spatial analysis tool. The steps followed by (Yeh et al, 2009), (Sander, 2007), (Jha et al, 2007), (Sreedevi et al., 2005) and (Sener et al., 2005) were used to classify lineament distribution of the study watershed.

3.2.1.5. Elevation thematic layer of the study watershed

It is studied that infiltrations tends to store at lower elevation rather than at the higher elevation (Ramu, and Vinay, 2015), therefore plains with lower elevation tend to retain infiltrations longer, favoring in higher groundwater recharge (Kumar et al, 2020) and vice versa for higher elevation. This is the reason why elevation should be considered in this study to assess groundwater potential areas in study watershed. In order to investigate topographic nature of the study watershed, SRTM DEM 30m*30m layer using a GIS 10.8_platform was used to calculate and map the elevation of current study watershed. Jenks classification techniques (GF, 1967) was used group the elevation of the current study watershed to characterize groundwater recharge favorites in each ranges supported by (Kumar et al, 2020).

3.2.1.6. Distance to river thematic layer of the study watershed

Area near to river is favorable for effective infiltration facilitates good groundwater recharge (Moghaddam et al, 2015). Study conducted by (Naghibi et al, 2020) shows that aquifers close to river increase high recharge rates than those located far from river.

The distance from river was generated by selecting spatial analyst tools, and then the resulting raster file was converted to lines using the conversion tools. Then after using the “Euclidean

distance function” in ArcGIS10.8 _platform, jenks classification method (GF, 1967) was used to classify distance to river of the study watershed.

3.2.1.7. Soil thematic layer of the study watershed

Soil characteristics are factors that controlling the water holding capacity and important prospects in delineating groundwater potential (Anbarasu et al, 2019). It has also a significant control on the infiltration and percolation rates into an aquifer (Murthy, and R. Pradesh, 2000). Therefore, soil conditions are influencing factor in groundwater recharge and runoff as it is the medium through which water must penetrate to get into the water table (Murthy, and R. Pradesh, 2000). The influence of soil texture on the effect of LULC change on groundwater recharge can be attributed to differences in water infiltration rates of different soil textures (Moghaddam et al, 2015), thus soil group having high sandy proportion have faster water infiltration rates and highly significant for varying the groundwater recharge, compared with silt and clay soils.

The soil layer of the study watershed was developed from the soil map of Ethiopia using the geo-processing clip toolbox in Arc-GIS 10.8 _platform.

3.2.1.8. LULC thematic layer of the study watershed

Classification of land use/cover for analysis was done based on their character to infiltrate water in to the ground. (Leduce et al, 2001), were found that one of its main contributions affects the volume of groundwater recharge into the aquifer as related to the changes in land utilization. Therefore, various land use/ land cover classes and their character to infiltrate water in to the ground and to hold water on the ground is depends on LULC types.

To develop land use land cover map of the study watershed, ERDAS IMAGINE version 2015_ platform was used to perform image analysis and image classification. Using ERDAS IMAGINE version 2015_ platform, selecting, and importing bands, sub-setting, layer stacking of the image based on the study watershed boundary, and other image enhancement techniques carried out and, where Landsat 8 (OLI) satellite image of 2020 with 30m*30m spatial resolution was used to develop land use/cover map of the study watershed. In this study supervised image classification technique using maximum likelihood algorithms was carried out to classify the images using training points by connecting each training points to Google

Earth Imageries. Supervised image classification technique was selected due to the researcher familiarity with study area and researcher’s knowledge of the actual LULC types present for selecting appropriate training areas in the image. For classification and validation, from Mantha watershed 109 (Appendix 1) ground truth control points (GCPs) were randomly collected through handheld GPS 72H during field observation time. These ground truth control points collected from fields were used to validate classified LULC classes using supervised classification techniques.

To classify LULC of the study watershed, the criteria given by (Anderson, 2001) was applied according to study watershed actual LULC. Hence, LULC classes and their descriptions are presented below.

Table 3-1: LULC Classes and their description of the study watershed

No	LULC classes	LULC class descriptions
1	Agricultural plantation	Perennial and annual cropland
2	Forest land	Areas composed of forest land.
3	Wetland	The area in which covered by the marshes
4	Bare land	The area in which covered by bare exposed rock, areas with little or no vegetation cover consisting of exposed soil.
5	Shrub land	Area dominated by shrub species that have medium vegetation (the land where the potential natural vegetation is predominantly grasses, grass-like plants, and bush lands).

3.2.1.9. Geomorphology thematic layer of the study watershed

(Rajaven et al, 2017), have explained about the features of various water-bearing geomorphological formations influence the occurrence of groundwater. Similar studies conducted by (Singhal, and Gupta, 1999) also noted the mapping of geomorphologic units significantly contribute in deciphering region of groundwater recharging zones and their potential production for groundwater exploration. Therefore, geomorphologic mapping is

important to identify landforms that have a direct control on occurrence of groundwater. Geomorphology layer of the study watershed was mapped from the geomorphology map of Ethiopia developed by ministry of agriculture) (MoA) using the geo-processing clip toolbox in Arc-GIS 10.8 _platform.

3.2.1.10. Geology thematic layer of the study watershed

The occurrence of groundwater is influenced by geological units (Rajaven et al, 2017) and this is the reason why particular attention must be considered to the geological units that affect the occurrence of groundwater because geological mapping serves as a basis for the study of groundwater condition in geological environment. Geological layer of the study watershed was generated by digitizing of a region formation from geological map of Ethiopia. Then after the study watershed geological formation image was clipped applying the shape file of the study watershed with the help of clip tool of the analysis tools of ArcGIS 10.8_platform.

3.2.2. Developing groundwater potential zones of the study watershed using AHP based analysis with GIS

The MCDM approach was used in this study is Analytical Hierarchy Process (AHP). It is a Multicriteria model for complex decision making by assessing multiple factors. The model stands for inputting influencing parameters that are accomplished by researcher (Kumar, and Krishna, 2018).The thematic layers of controlling variables were tested by the AHP techniques using normalized weights to evaluate the GWPZs of the study watershed. Pairwise comparison matrix was created based on the number of selected controlling variables in study watershed such as (Geology, LULC, rainfall, soil groups, geomorphology, slope, drainage density, distance to river, elevation and lineament density) for the GWPZs mapping (Saaty, 1980). The relative importance (relative weight) of a one variable on groundwater availability related to another variable was evaluated based on the Saaty's 1–9 scale (Saaty, 1980). Carefully keeping the procedures of evaluation of groundwater potential zone, high weights were ranked to imply good groundwater availability while low weights were ranked to imply poor groundwater availability (Rahmati et al, 2015). Ranking of the variables were defined using created a pairwise comparison matrix based on the AHP techniques.

Table 3-2: Saaty scale of rating influence of factors

No	Degree of Influence	Meanings of terms	Explanation about meanings of terms
1	1	Equal suitability	Two factors influence equally to the objective
2	2	Intermediate suitability	When compromise should be decided
3	3	More suitability	Experience and decision slightly one over the other
4	4	Intermediate suitability	When compromise should be decided
5	5	Much more suitability	Experience and decision strongly favors one over the other
6	6	Intermediate suitability	When compromise should be decided
7	7	Very much more Suitability	Experience and decision are very strongly to favors one over the other.
8	8	Intermediate suitability	When compromise should be decided
9	9	Absolutely more Suitability	Within some evidence of favoring one over the other is of highest possible suitability

Source: (Saaty, 1980)

A. Constructing relative weights for GWP controlling variables using AHP

The relative weight for identified thematic layers (Geology, LULC, rainfall, soil groups, geomorphology, slope, drainage density, distance to river, elevation and lineament density) were assigned keeping mind one of them has more influence to the groundwater occurrence than the other (Tesfaye, 2012). The GWP controlling variables values are scaled based on the saatty scale (Saaty, 1980).

B. Assessing Pairwise comparison matrices for weighted thematic layers and their normalized pairwise comparison matrix

Pairwise comparison matrices of assigned weights to ten selected thematic layers in this study watershed and each class of them are constructed using (Saaty, 1980) AHP techniques. Comparisons were conducted based on the evaluation criteria developed by (Saaty's, 1980) for ten GWP controlling parameters considered in this study watershed and the weight for each parameter was determined. The normalized pairwise comparison matrix was prepared by

dividing each value in the column in the pairwise comparison matrix by the sum of the column.

C. Normalized Principal Eigen Vector and Consistency computation

The weight assigned to each parameter must be checked. To check whether the comparison is consistent or not, the consistency check inputs such as λ_{max} as suggested by (Saaty, 1980) was performed first by multiplying the weight of the first criterion with the total value that was found in the pairwise comparison matrix.

The consistency ratio was calculated to evaluate the appropriateness of the weights applied to each controlling variable using the equation $CR = CI/RI$ (Saaty, 1980).....3.3

Where, RI is the average of the resulting consistence index supported by Saaty (1980) and CI is consistency index. Consistence index $(CI) = (\lambda_{max} - n) / (n - 1)$ (3.4)

Where λ_{max} is the Principal Eigen value and n is the number of parameters involved in the comparison.

Table 3-3: Saaty’s ratio index for different values of n

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49

Source: (Saaty, 1980).

D. Overlaying Thematic Layers Using Arc GIS10.8_ platform

All ten thematic layers considered in this study were reclassified and arranged in similar cell size 30m*30m using Arc GIS10.8_platform before performing overlay analysis. After the AHP analysis has been completed, the output potential map developed from weighted overlay analysis by integrating selected ten layers in Arc GIS 10.8 raster calculator and Jenks optimization methods (GF, 1967) was used to group potential zones.

3.2.3. Validating the developed groundwater potential zones using well data

This study has been carried out using GIS and RS. These models used for this study are believed to be scientifically not acceptable if not validated. Therefore, the developed

groundwater potential maps using the GIS and RS under AHP method was compared with data of wells in this study watershed.

The well data were obtained from South West Ethiopia peoples' Region Water and Irrigation Development Bureau and Zonal water offices. Well data (Appendix: 2) were used to validate the result of this study. Among 37, 2 wells are dry wells, and only used to validate low category potential zone. Since, there is no general classification methodology for different yields data, the approaches followed by (GSE, 2013) was used to classify well yields into four categories to validate model result with some modification accordingly to obtained well data. Yields ranges were classified into three groups with 30 l/min to 60 l/min low, 30 l/min to 300 l/min moderate, and >300 l/min high (GSE, 2013). The yield ranges grouped under (GSE, 2013) were slightly different with current well yield and some modification taken by researcher to classify yields into four groups as <60 l/min as low, between 60-180 l/min moderate, 180 l/min to 348 high and >348 l/min very high.

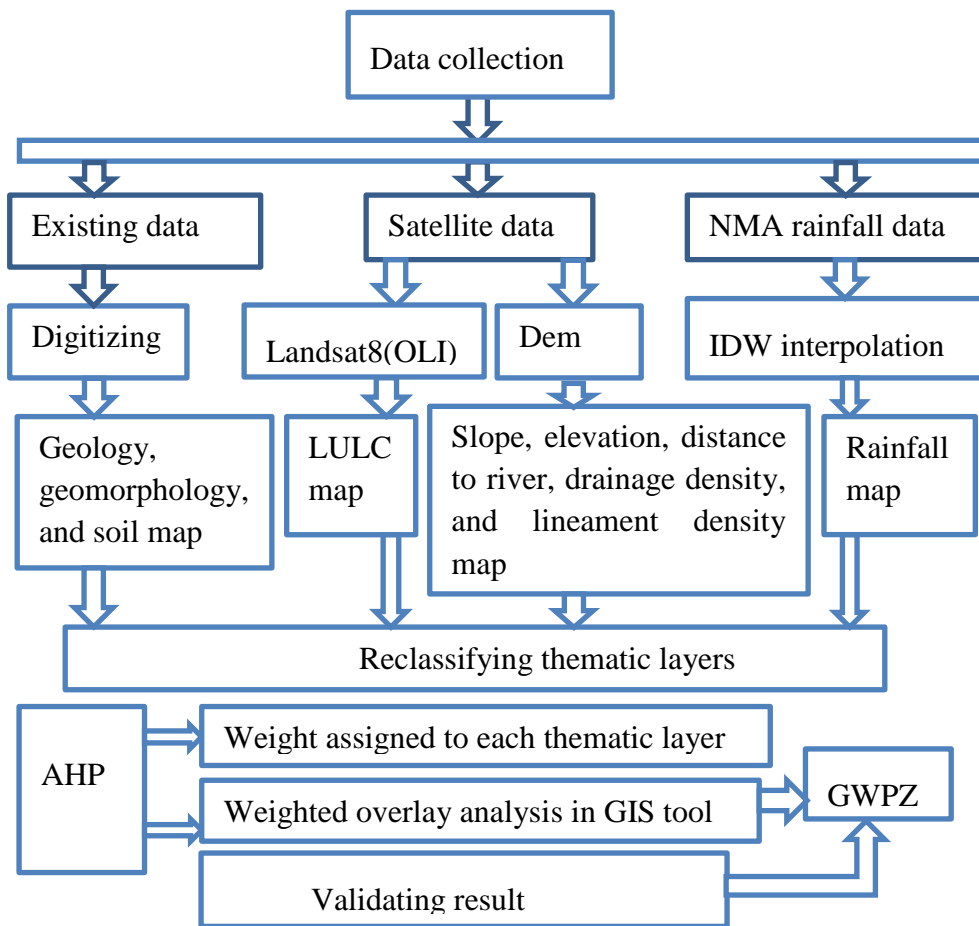


Figure 3-2: Flow of the Methodology

4. RESULTS AND DISCUSSION

4.1. Characterization of Groundwater Controlling Thematic Layers

4.1.1. Reclassified slope layer of the study watershed

Slope is included within other thematic layers were developed in this study. The reason why it included in this study is study watershed had scattered distribution of slopes creates possible variations on groundwater distributions from zones to zones. The dependency of slopes on groundwater potential was determined by relating groundwater potential to topographic wetness index (Achu et al, 2020). The slope of the study watershed was grouped into five separate classes such as 0-2⁰ (flat to very gently sloping), 2-5⁰ (Gently sloping), 5-10⁰(Sloping), 10-15⁰(Strongly sloping), and greater than 15⁰(Steep sloping). Topographic attributes of elevation also was grouped into five separate classes to verify each slope classes.

Table 4-1: Role of slope and its rank as per suitable for groundwater potential formation

Factor classes considered	Values(degree)	Area coverage(ha)	Groundwater suitability
Flat to very gently sloping	0-2	26495.2	Very high suitability
Gently sloping	2-5	36072.3	High suitability
Sloping	5-10	30685.5	Moderate suitability
Strongly sloping	10-15	19945.2	Low suitability
Steep sloping	>15	8345.5	Very low suitability

The first two classes (that are, 0-2⁰, and 2-5⁰) occupied 62567.5 hectares of the study watershed and they were ranked weight value of higher. These zones facilitate high infiltration of the study watershed favored good chances of groundwater potential formation. GPS points of inventory data high yield well were displayed fallen on first two classes. This further verified the category of high groundwater potential zone was identified from these slope zones, and the result is proportional with case studies conducted by (Magesh et al, 2012). These regions also compared with produced topographic wetness index map of the study watershed marked by fully and partly red marked in(Figure 4:1) indicating higher index value shows high potential of water accumulated due to low slope agreed with similar study conducted by (Achu et al, 2020). Therefore, the result of this study figured that slope category

fallen under $0-2^{\circ}$ and $2-5^{\circ}$) are more favorable for groundwater potential formation in this study watershed.

Most of study watershed was occupied by slope class $5-10^{\circ}$ which covers 30685.5ha next to gently sloping. This class facilitates moderate groundwater suitability in study watershed and its category was compared with TWI value computed in this study in line with (Achu et al, 2020) showing proportionality of analysis.

The other last fourth and fifth classes of the study watershed was occupied by $10-15^{\circ}$ and $>15^{\circ}$ which cover 19945.2ha and 8345.5ha. These last two zones facilitate high runoff made poor infiltration resulted a limited chance of groundwater availability was expected in these zones. This inverse relationship of groundwater potential formation and slopes are further supported the same titles reported by (Yeh et al, 2016). Lower TWI value observed in this study was indirectly proportional to the last fourth and fifth slope classes that are very high slope category ($10-15$, and >15) is acceptable because groundwater potential evaluation investigated by (Achu et al, 2020) was directly proportional to TWI value and this study results also shows similarity with it. Therefore, there is limited chance to water store in last slope classes because the ratio of slope to its topography is low in higher slope region in this study and also these regions are not supported by (Achu et al, 2020) on their groundwater study work.

In generally, slope was ranked seventh influencing factor regarding relative weighting rated in AHP and the first two classes are best classes to determine groundwater potential sites in this study watershed.

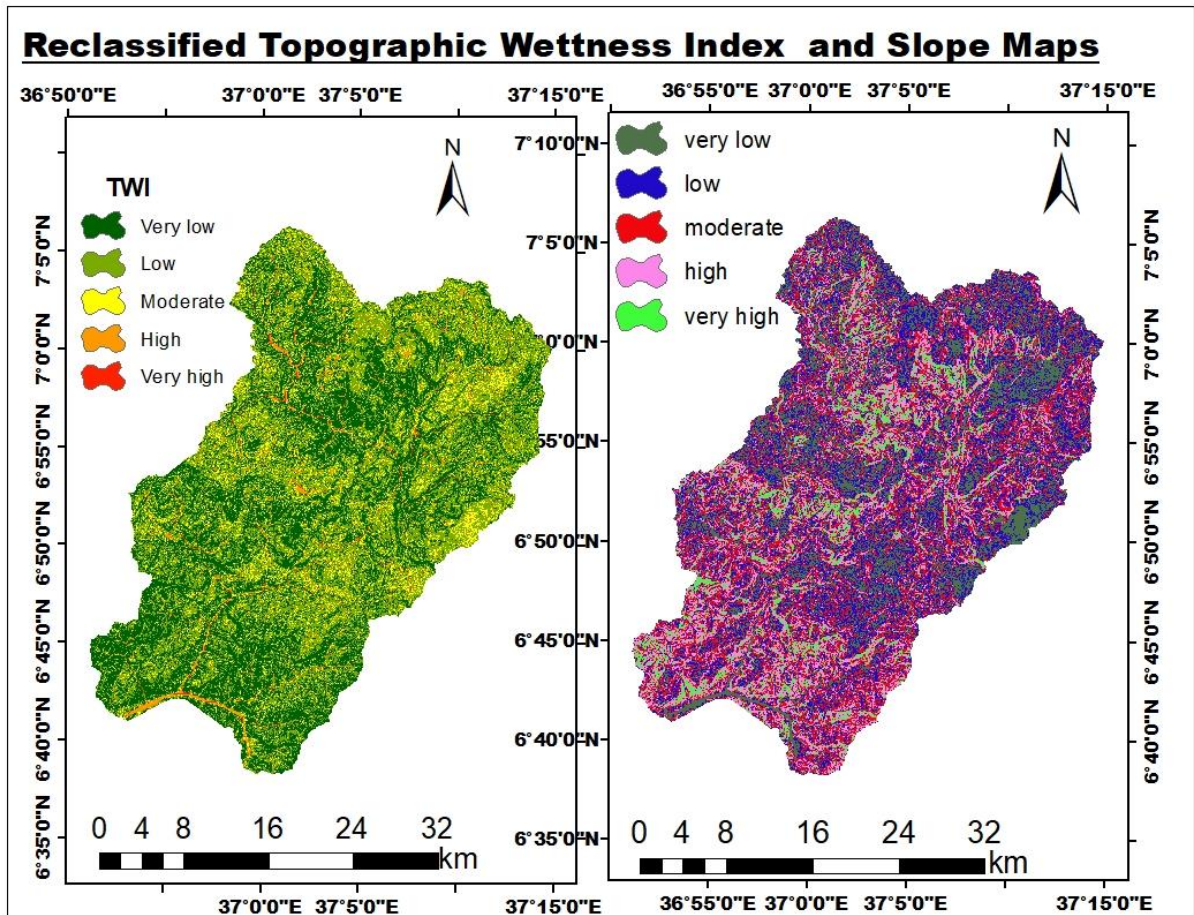


Figure 4-1: Reclassified slope and topographic wetness index map of the **Study Watershed**

4.1.2. Reclassified lineament layer of the study watershed

The summarized results in the (Figure 4:2) and (Table 4:2) shows the spatial distributions of lineament densities. The magnitude of very high lineament distribution calculated from the model greater than 0.662 km/km^2 was categorized under very high groundwater potential which covers total entire area of 39.015 km^2 . Next to this, 0.498 to 0.662 km/km^2 grouped under high groundwater potential which covers 135.413 km^2 of the study watershed. In this study watershed the very high and high groundwater potential zones were investigated from a place where area near and inside higher lineament distributions zones (comparing produced GWPZ (Figure 4:11) and lineament layer (Figure 4:2) of the study watershed. High well yields were examined in relation to these high lineaments mapped in (Figure 4:2) and high

groundwater potential zone (Figure 4:11). Therefore, these categories play a great contribution to create high groundwater potential marked by partly red and clear sky or magnitudes of lineaments that are greater than 0.662 km/km^2 and lie between 0.498 to 0.662 km/km^2 of the study watershed is also more related to potential study conducted by (Nampak et al, 2014). The third group of lineament distribution that is 0.352 - 0.498 km/km^2 which covers total area of 205.904 km^2 was categorized under moderate groundwater potential in this study watershed. This class was matched with groundwater potential case study reported by (Jha et al, 2007) and contributed as moderate potential sites.

A majority of the study watershed is occupied by low to very low lineaments (0.173 - 0.352 km/km^2 , and 0 - 0.173 km/km^2) which cover total area of 835.335 km^2 and its lineaments distributions are scattered in all entire regions. Low well yields were examined in relation to low lineaments mapped in (Figure 4:2) and low groundwater potential zone (Figure 4:11). Therefore, limited chance of groundwater availability was expected from last classes (0.173 - 0.352 km/km^2 , and 0 - 0.173 km/km^2) in this study is also similar to potential studies observed by , (Sreedevi et al., 2005), and (Sener et al., 2005).

In generally, lineament density was ranked third factor next to rainfall based on the weighting value derived from AHP and the direct relationship of lineaments with groundwater potential formation analyzed in this study using GIS model shows a good agreement to that of (Nampak et al, 2014). Therefore, the very high and high groundwater potential zones are distributed along major lineaments (Figure4:2) and zones with high lineament distributions are the most crucial zones and should be considered high chance for groundwater drilling.

Table 4-2: Lineament distribution and its rank as per suitable for groundwater potential

Factor rate	Values (km/km^2)	Area coverage(km^2)	Groundwater suitability
Very high	>0.662	39.015	Very high suitable
High	0.498 - 0.662	135.413	High suitable
Moderate	0.352 - 0.498	205.904	Moderate suitable
Low	0.173 - 0.352	225.411	Low suitable
Very low	0 - 0.173	609.927	Very low suitable

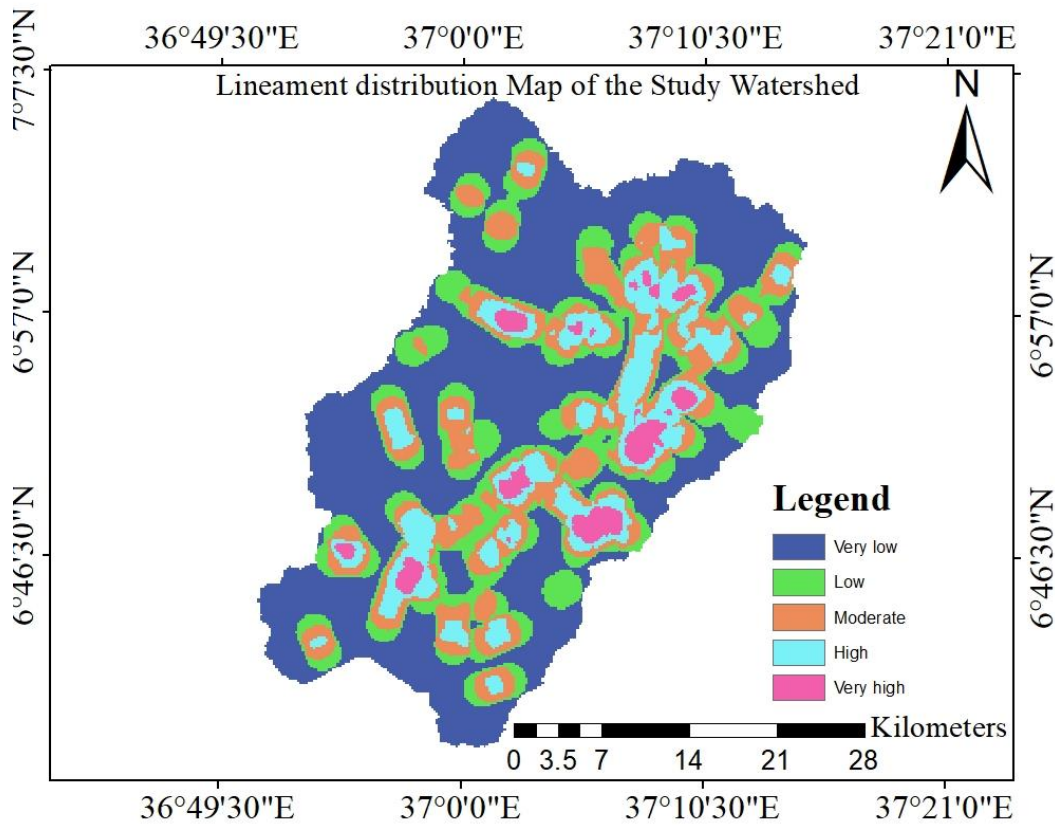


Figure 4-2: Reclassified lineament Map of the Study Watershed

4.1.3. Reclassified soil layer of the study watershed

The reason why this study used as a thematic layer is different soil groups plays non uniform contributions in terms of infiltration characteristics of the study watershed. Based on the (Tewodros, 2005), different soil groups are characterized by varied infiltration characteristics and their attributes to groundwater potential formation is also varied. The identified major (dominant) soil types of the study watershed were dystric fluvisols, dystric gleysols, dystric nitosols, eutric cambisols, eutric nitosols, leptosols, and orthic acrisols as shown table below.

Table 4-3: Soil groups and their areal and percentage coverage in the study watershed

NO	Soil groups	Area coverage(km ²)	Percentage (%)
1	Dystric Fluvisols	83.18	6.843
2	Dystric gleysols	5.293	0.435
3	Dystric nitosols	361.312	29.722
4	Eutric cambisols	430.6459	35.426
5	Leptosols	38.324	3.153

6	Orthic Acrisols	253.75	20.874
7	Eutric Nitisols	43.13	3.548

The result show that about one-third of the study watershed is occupied by eutric cambisols 430.6459km² (35.426%), followed by dystric nitisols 361.312 km² (29.722%), orthic acrisols 253.75 km² (20.874%), dystric Fluvisols 83.18 km² (6.843%), eutric nitisols 43.13 km² (3.548%), leptosols 38.324 km² (3.153%) and dystric gleysols 5.293 km² (0.435%).

The infiltration rate of identified soil groups of the study watershed were tabulated below as per suitable for groundwater potential formation followed by the same approaches (Yeh *et al.*, 2008), (Jha *et al.* 2007), (Dawit Yihunie and Afera Halefom 2020), (Tewodros (2005), Ikegwonu E. S. *et al* (2021), Kabeto, J *et al* (2022).

Table 4-4: Soil groups and its rank as per suitable for groundwater potentiality

Soil group	Infiltration rate of soil group	Groundwater potentiality
Dystric Fluvisols	Very high infiltration	Very high potential
Dystric gleysols	Low infiltration	Low potential
Dystric nitisols	Moderate infiltration	Moderate potential
Eutric cambisols	High infiltration	High potential
Leptosols	Low infiltration	low potential
Orthic acrisols	Moderate infiltration	Moderate potential
Eutric nitisols	Moderate infiltration	Moderate potential

❖ **Characterizations of soil groups in this study watershed with other studies**

➤ **Cambisols group**

This soil group dominated a large portion of the study watershed relatively high in Southern region than Northern region which covers total area of 430.6459 km² (29.722%) of the study watershed. Cambisols attributes high infiltration capacity to recharge groundwater than other soil groups identified in this study watershed. Because study conducted by (Tewodros, 2005) shows that this soil group is highly permeable when compared with soil groups of this study. In addition these soil groups are characterized by containing high silt and sand content favors faster infiltration rate than other soil groups identified in this study watershed and the result further checked from (FAO, 2003). This is the reason why eutric cambisols was ranked high potential than the others and its contribution was further verified with produced high potential zones from it and displayed well yields fallen on it.

In generally, high well yields which were fallen on eutric cambisols region better verified by falling on high groundwater potential region, but it does not mean that high groundwater potential distributions where identified from only the area mapped by this soil group due to factors such as lower distance to river, lower slope, lower elevation and others.

➤ **Dystric nitosols**

Next to eutric cambisols, dystric nitosols dominated very large portions in northern highland (Figure 4:4) area and very small portion in Sothern area of survey watershed which covers total area of 361.312 km² (35.426%). Nitosols covers an extensive area of the agricultural plantations in the northern region of the study watershed. This was related with study conducted by (Elias *et al.*, 2019) indicated that the agroforestry-based system of the south-western highlands, nitosols support both garden and forest coffee and enset. This means that LULC class such as garden and forest coffee, enset, banana, mango, and others which are perennial existed within contribution of infiltrated water. In addition, similar study conducted by (Water Resources Consulting Service(WRCS), 2013) show that dystric nitosols have a good permeability and favorable structure. Regarding (Water Resources Consulting Service(WRCS), 2013) and (FAO, 2003), and other similar study conducted by (Dawit and Afera, 2020) , this soil group was ranked moderate potential.

➤ **Dystric gleysols**

Soil map of the study watershed also show that dystric gleysols occupied very few part in northern and central region which covers total area of 5.293 km² (0.435%). It was ranked low potential due to low infiltration capacity to recharge groundwater (Yeh et al, 2009). The rank was verified by produced groundwater potential zone identified from the area mapped by this type of soil group which was low potential.

➤ **Leptosols**

Leptosols dominated in southern parts and very few in central region of the study watershed which cover total area of 38.324 km² (3.1530%). This soil group also ranked low potential due to low infiltration capacity to recharge groundwater supported by (Yeh et al, 2009). It has less influence interims of both dominance and contribution. Most of groundwater potential distribution along this soil group was low potential, but somewhere moderate to high

groundwater potential zones were identified close to it or inside it. This is due to this soil group was identified somewhere near rivers and other factors in this study watershed my favor varied distributions of groundwater.

➤ **Orthic Acrisols and**

The result shows that about one-fifth of the study watershed is dominated by Orthic Acrisols which covers 253.75 km² (20.874%) and its distribution was scattered in all entire region. Orthic Acrisols group was ranked moderate potential in this watershed and further compared with the result of (Ikegwuonu et al, 2021) and it shows fair agreement.

➤ **Eutric Nitisols**

Eutric Nitisols was occupied very few in both northern and south eastern region of the study watershed which covers total area of 43.13 km² (3.548%). This soil group was ranked moderate potential based on its contribution of infiltrations (Dawit and Afera, 2020). Most of Eutric Nitisols group was identified from the area covered by agricultural plantations and also very few coverage was identified from forest land and therefore, the rank given for agricultural plantations is suitable for this soil group.

➤ **Dystric Fluvisols**

The result shows that 6.843% of the study watershed is covered by Dystric Fluvisols which covers 83.18 km². This soil group was distributed in all region of the study watershed with very small area coverage (83.18 km²) and it was grouped under higher groundwater potential (Yeh et al, 2009).

In generally, it was given more attention for the first class (Cambisols groups) due to its both highest areal coverage (35.426%) and facilitates fast infiltrations to subsurface. This was supported by other author (Tewodros, 2005) in groundwater studies.

Next to Cambisols groups, the Dystric Nitisols also highly dominated in northern region and low in other region which covers total entire area of 361.312 km². Its high dominance in northern region and lower distribution in other region creates possible variation in groundwater distribution. In LULC class, cultivation land was most dominant class in this soil

group class and its relation was discussed above and also verified with other study conducted by (Elias et al, 2019)interims of infiltrations characteristics.

Therefore, these groups are most influencing groups among other groups were identified in this study watershed which hold total area of 64.848% and over all soil groups influenced 10.3 %.

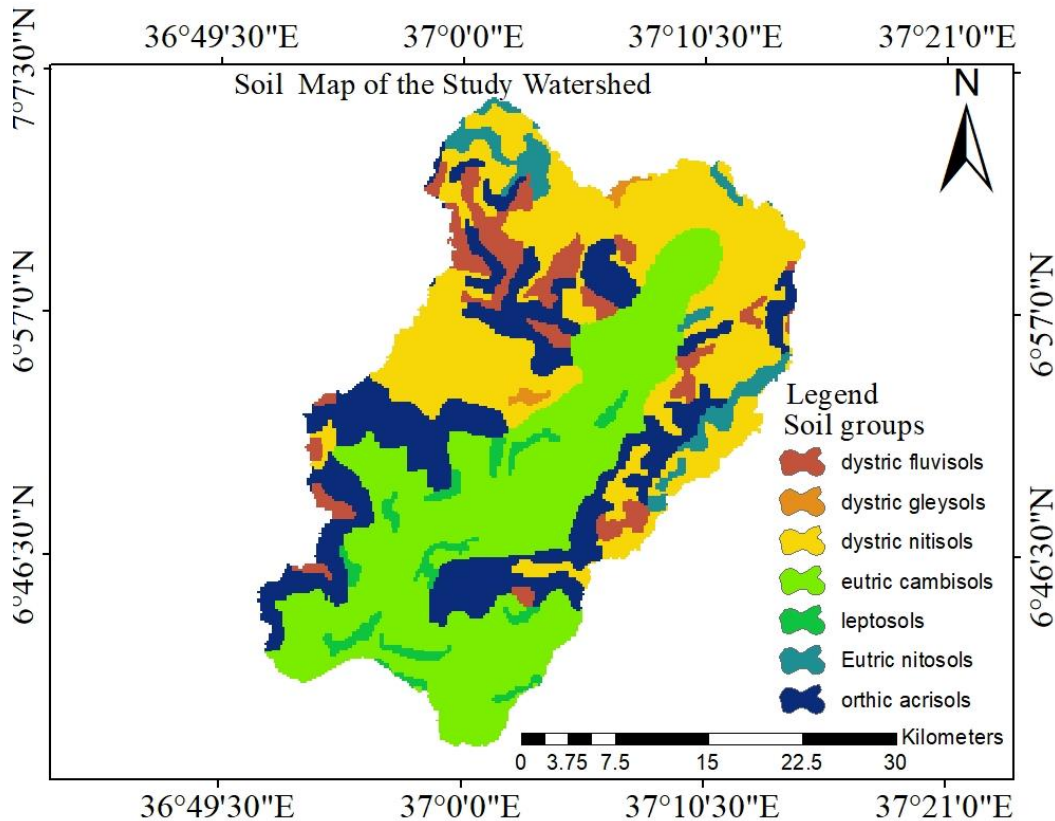


Figure 4-3: Reclassified Soil Map of the Study Watershed

4.1.4. Reclassified geomorphology layer of the study watershed

Geomorphology is the study of various landforms related to the groundwater occurrence (Ramu, and Vinay, 2015). Therefore, this study considered different landforms are important features in evaluating the groundwater potential formation.

There are four types of geomorphologic features were identified in the study watershed namely, slope, summit, bottom/plain and plat zones. The geomorphology of the study watershed was classified in terms of groundwater potentiality supported by (Jha et al, 2007).

Slope is highly dominated in southern region and scattered all over central and northern region which covers total area of 945.275 km² in this study watershed. More than 77% of the study watershed is classified as slope landforms. Slope landforms are widely found in the study watershed have lower to higher topography and infiltration can happen more than summit region, hence assigned moderate potential formation. Low slope landforms are normally favorable for groundwater potential formation, and on other hand high slope landforms are negatively related to groundwater potential formation shows direct relationship with other study conducted by (Kumar et al, 2020).

Following slope, the central region, and northern part of the study watershed is partly dominated by summit terrain which covers total area of 197.705 km². In the present study watershed, summit landforms with high topography where it has more runoff attribute low groundwater potentials hence, given low weight. Since, summit is a point on a study watershed that is higher in elevation than surrounding or adjacent to it, this class was classified as low potential according to (Kumar et al, 2020).

Plain/bottom region is identified from area near rivers in both northern and southern region which covers total entire area of 44.315 km². Bottom landform was observed from a place where high topographic wetness index value generated and generally showed high groundwater potentials. Because of the discharging of rivers which are found very close to drilled borehole supported with visiting the place where such plain land locating discussed in section (4.1.7) wells locating on plain lands which are close to river. High measured well yields were fallen on this region, hence, given high weight to this class. In generally, this land forms are very near to river and also close to faults favoring good option to create groundwater potential and this direct relationship was verified by other similar authors (Achu et al, 2020), and (Naghibi et al, 2020).

Very few in southern lowland portion are situated flat land which covers total area of 28.436 km² of the study watershed. Flat landforms were identified only southern region occupies very few areas a place where study watershed join lower Omo river basin. It was assigned very high potential compared with other landforms because this region was investigated from very lower topography, high value topographic wetness index, and distance close to river and very

low slope. Therefore, in relation to examined TWI, short distance to river, and lower slope that are directly proportional to groundwater potential, the flatter the elevation is the better are the probability for groundwater accumulation in such flat topography landforms.

In generally, geomorphology grouped 6th factor next to LULC based on the weighting value derived by AHP and this study suggests that it is better to drill groundwater inside or close to flat and bottom landforms than the area occupied by slopes and summit.

Table 4-5: Geomorphology units and their ranks as per suitable for groundwater potential

Geomorphology units	Groundwater potential formation	Area coverage(km ²)
Flat	Very high	28.436
Plain/Bottom	High	44.315
Slope	Moderate	945.275
Summit	Low	197.705

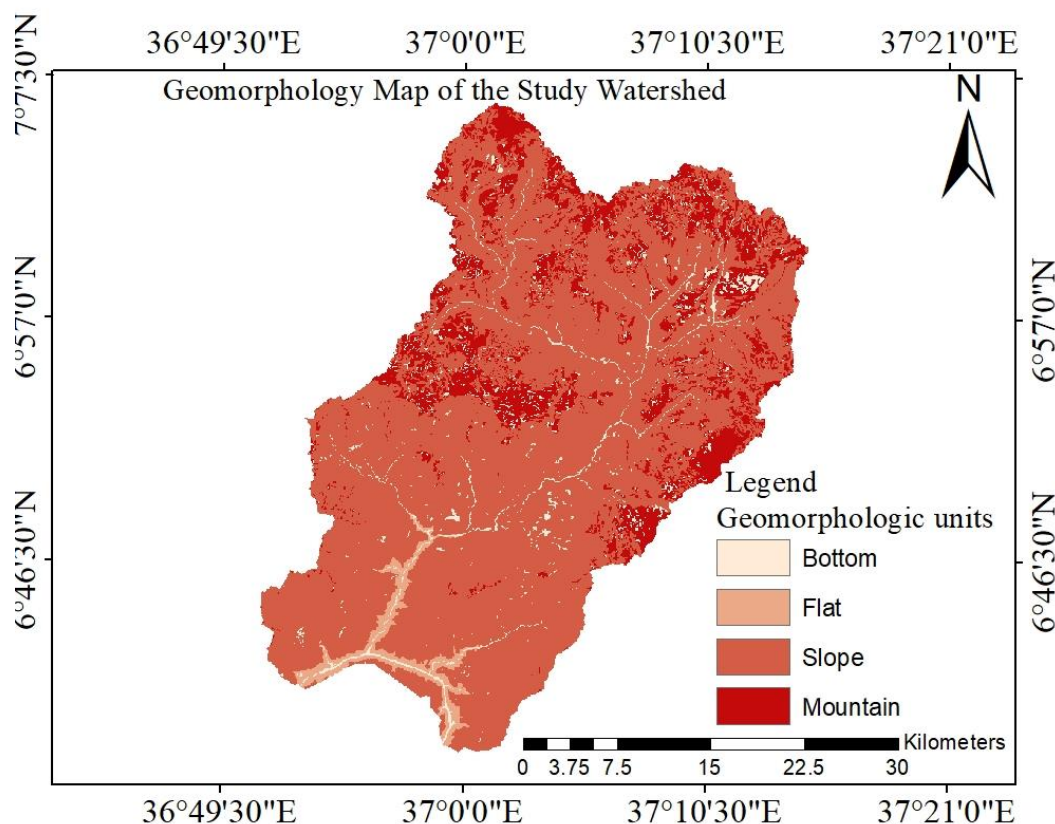


Figure 4-4: Reclassified Geomorphology Map of the Study Watershed

4.1.5. Reclassified elevation layer of the study watershed

In present study watershed elevation had influenced percentage influence of 3.2% which was rated in AHP tool, and ordered in last rank.

Very low elevation values less than 1108.6m which covers 166.11 km² and are observed in southern lowland region which is very low slope of the study watershed. Lowest topographic feature was classified within 'very high' groundwater potential owing to the lower slope in southern region attributes high infiltration, and assigned factor value of 5. The study investigated by (Ramu, and Vinay, 2015) indicates lower elevation is more favorable to create groundwater potential formation by storing water at plain surface landforms and the study conducted by was proportional to this study. The examined high TWI value in Figure 4:1 from this topographic region also shows the direct relationship was supported by (Achu et al, 2020).

Low elevation values 1108.7-1505.1m were observed from southern and central region of the study watershed which covers 240.22km². Low topographic feature was classified within 'high' groundwater potential and assigned weight value of 4 because obtained high value of TWI Figure4:1 supported by (Achu et al, 2020).

Therefore, the above two classes which are less than 1108.6m and lies between 1108.7-1505.1m are most important classes having lower slope to store water because lack of well data from first class topographic feature region was further validated with derived topographic wetness index supported by (Achu et al, 2020) and the second class was verified with well yield of good.

A moderate topographic value 505.2-1867.1m was investigated from all regions, which covers 327.12 km². Moderate topographic feature was classified within 'moderate' groundwater potential and assigned weight value of 3. This class also verified with TWI value and it shows good correlation with produced TWI map (Figure 4:1).

Very high and high categories 2186.1-2798m and 1867.2-2186 are dominated in northern region and scattered all over entire region, which cover 189.87km² and 291.78 km² respectively of the study watershed. They classified within 'very low to low' groundwater potential and assigned weight value of 2 and 1 respectively. Nevertheless, most part of the study watershed was dominated by highland region, but high well yields and high potential

zones were investigated from this region. It is believed that there is no single condition that determines such factor, but a single condition is determined with other conditions. Moreover, in this study case this is due to well near to river even if within higher topography land forms is high potential because of distance to river which is less than 600m , high topographic index value at that area and other factors contributed to discharge wells and favored aquifer system to create water.

Generally, this study suggests that it is better to drill groundwater from first two classes than other classes. This is because the first two classes were investigated from the region of lower slope, trachyte, flat landforms, and majority of bottoms/plains, and eutric cambisols.

Table 4-6: Elevation category and its rank as per suitable for groundwater potential formation

Factor class	Elevation(m)	Groundwater potential formation	Areal coverage(sq.km)
Very low elevation	600-1108.6	Very high potential	166.1
Low elevation	1108.7-1505.1	High potential	240.22
Moderate elevation	1505.2-1867.1	Moderate potential	327.12
Low elevation	1867.2-2186	Low potential	291.78
Very low elevation	2186.1-2798	Very low potential	189.87

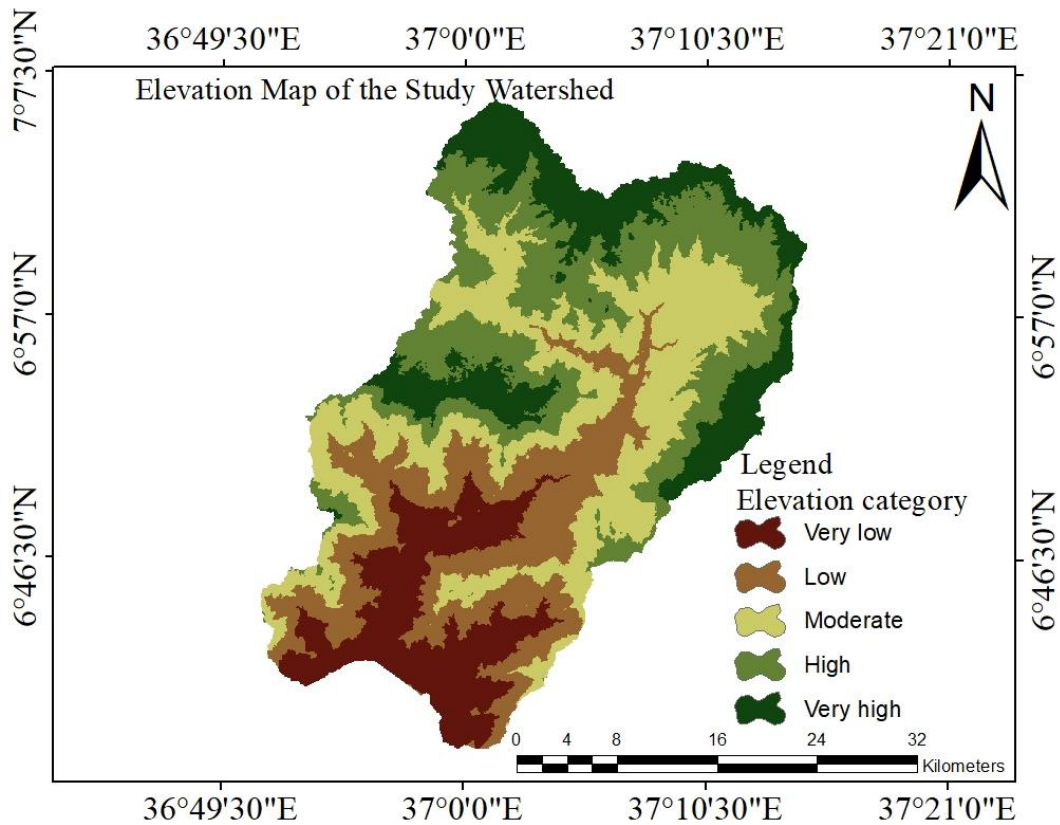


Figure 4-5: Reclassified Elevation Map of the Study Watershed

4.1.6. Reclassified drainage density layer of the study watershed

Areas with high drainage density provide more runoff and less permeability. The classified drainage densities were ranges from 0 - 3.643 km/km² and classified as very high potential (0-0.75km/km²), high potential (0.75-1.5km/km²), moderate potential (1.5-2.25km/km²), low potential (2.25-3km/km²) and very low potential (>3km/km²) as shown table below here.

Table 4-7: Factor of drainage density and its rank as per suitable for groundwater availability

Factor classes	Values (km/km ²)	Area coverage(square kilometer)	Groundwater potentiality
Very low drainage density	<0.75	456.554	Very high potential
Low drainage density	0.75-1.5	344.915	High potential
Moderate drainage density	1.5-2.25	291.769	Moderate potential
High drainage density	2.25-3	111.957	Low potential

Very high drainage density	>3	10.399	Very low potential
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The drainage distribution less than $0.75 \text{ km}^2/\text{km}^2$ grouped under very low drainage, which covers 456.5 km^2 of the study watershed. This means that greater than 30% of the study watershed is characterized with very low drainage density.

Low drainage distribution lies between $0.75\text{-}1.5\text{km}^2/\text{km}^2$ of the study watershed which covers the total area of 345 km^2 . Based on the study conducted by (Allafta et al, 2021), this class was classified within high' groundwater potential and high groundwater zone was identified from this category and, therefore, the same approaches followed in this study and further verified with proportional result conducted by them.

In generally, most of the high potential regions in the study watershed had lower drainage density. Therefore, groundwater potential zones of the study watershed were investigated in this study is good in the area of low and very low drainage density.

Drainage distribution of value ($2.25\text{-}3\text{km}^2/\text{km}^2$), and ($>3\text{km}^2/\text{km}^2$) occupied 112.1 km^2 and 10.4 km^2 of the study watershed respectively and they categorized under high and very high drainage. These class are not this much important, but least important in this study and other study conducted by (Allafta et al, 2021). In this study highest drainage pattern which covers 0.85% (10.4km^2). When this study compared with other study conducted by (Allafta et al, 2021), groundwater potential zones are poor in areas of high and very high drainage density and, relatively fair in the area of moderate density ($1.5\text{-}2.25\text{km}^2/\text{km}^2$).

Generally, the percentage influence of drainage pattern in this study was 3.4% and the first, and second classes are most important potential class.

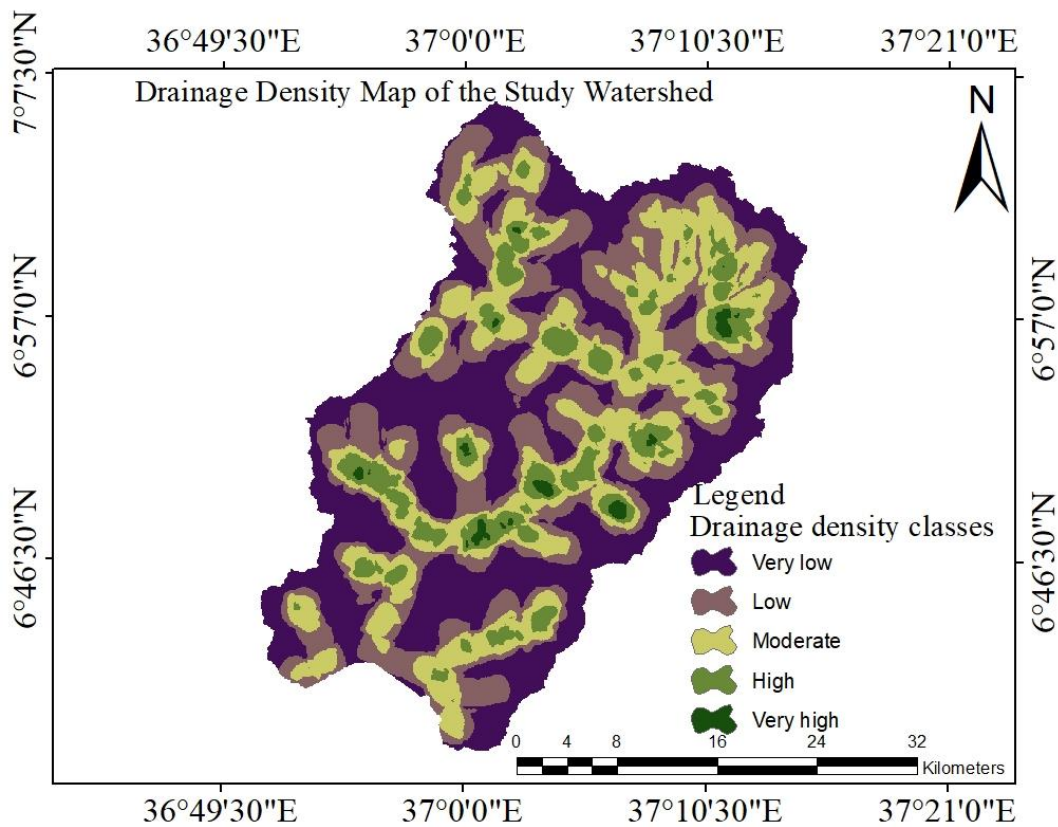


Figure 4-6: Reclassified Drainage Density Map of the Study Watershed

4.1.7. Reclassified distance to river layer of the study watershed

The very important first three classes are occupied (that are, 0-213.8, 213.81-449.71, 449.72-700.37m) which cover 78.3%, and the other two classes far from rivers (that are, 700.38-995.26 and 995.27-1879.94) cover 21.7% of the study watershed.

Very low distance to river values less than 213.8m was identified from very close to river which covers 359.6km² of the study watershed. Very low distance was classified within 'very high' groundwater potential and assigned weight value of 5. Good potential zones in the study watershed had lower distance to river values in this study is matched with similar cases verified by (Moghaddam et al, 2015). This class was compared with the related factors such as, bottom (plain area near to river), TWI, and well yields with visiting well sites close to river. Distance to river is one known factor in groundwater potential study conducted by (Moghaddam et al, 2015). Their finding verified that area near to river which is less than distance to river 600m is favorable for groundwater potential formation. Based on this the first

category of distance to river is most potential is acceptable which is 30% less than study conducted by (Moghaddam et al, 2015). This study also show that high TWI value was identified from first class reflecting accumulation of water close to river especially river bottom area verified in geomorphology mapping of this study is also related with it. Moreover wells drilled at nearly such location within the study watershed recorded high yield rate in the first class. Wells drilled from near river produced high yields were further verified by visiting site observation supported with photo camera (appendix 4).

Low distance to river values lies between 213.8m to 449.72m was identified from also close to river which covers 335.5km² of the study watershed. Low distance to river was classified within high groundwater potential and assigned weight value of 4. This category also less than distance to river which is favorable for groundwater potential formation suggested by (Moghaddam et al, 2015) and therefore, it shows good agreement with (Moghaddam et al, 2015). This class also verified with produced TWI map and agreed with (Moghaddam et al, 2015).

In generally, the first two classes are below recommended distance and more acceptable comparing with other study (Moghaddam et al, 2015). Therefore, it is better to drill groundwater from distance to river less than 600m.

The third class was also between recommended distances having distance value of 449.72-700.37m which covers 256.4 km² of the study watershed. Moderate distance to river was classified within moderate groundwater potential and assigned weight value of 3. This range also lies between recommended distance, and 100m greater than it lies and play moderate potential because distance below recommended is greater than distance above recommended which was explained above.

The fourth and fifth classes are last and least important classes attributed poor potential zones in study watershed had higher distance far from river. Low TWI value was generated from these distances value further reflecting low water stored within these distances which are far from river.

In generally, study conducted by (Naghibi et al, 2020), and (Moghaddam et al, 2015) shows that aquifers close to river increase high recharge rates than those located far from river is

fully applicable for first two classes in this study because the first two classes are below 600m. In present study watershed, distance to river had influenced percentage weight of 3.5% which was rated in AHP tool, and ranked in 8th.

Table 4-8: Distance to river and its rank as per suitable for groundwater potential formation

Factor class	Distance to river(m)	Areal coverage(km ²)	Groundwater potentiality
Very low distance	<213.8	359.6	Very high potential
Low distance	213.81-449.71	335.5	High rank
Moderate distance	449.72-700.37	256.4	Fair
High distance	700.38-995.26	182.8	Low
Very high distance	995.27-1879.94	81.3	Very low

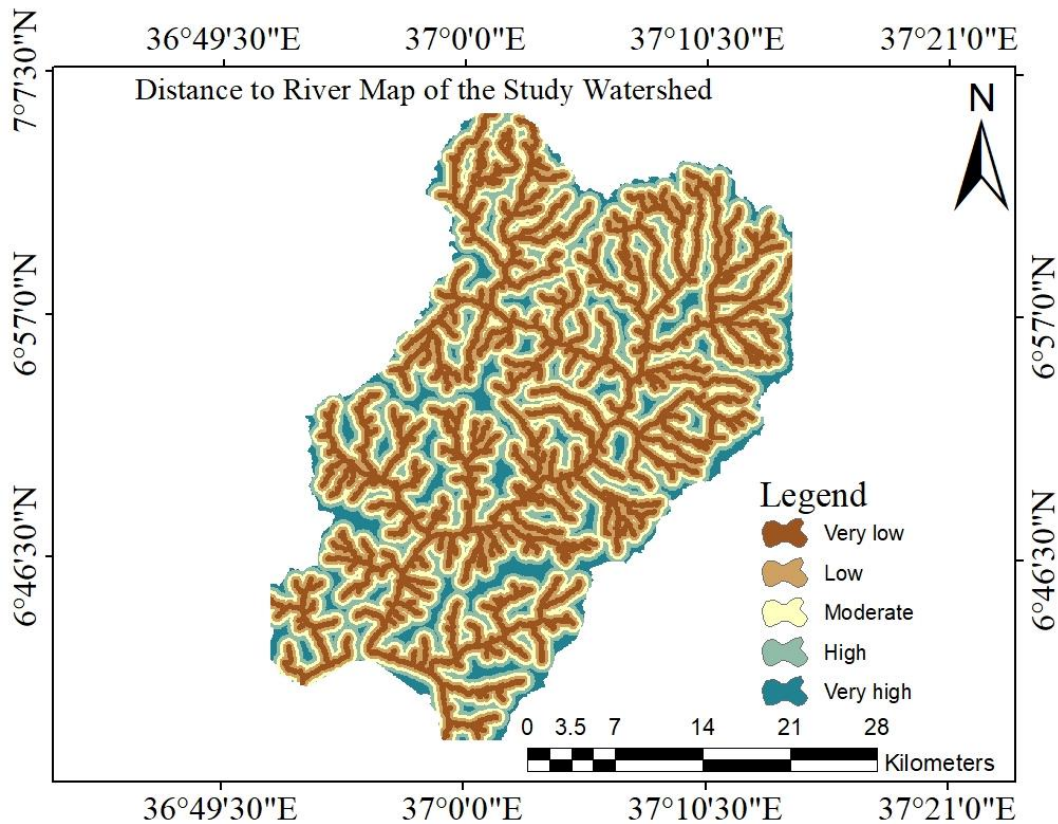


Figure 4-7: Reclassified Distance to River Map of the Study Watershed

4.1.8. Reclassified rainfall layer of the study watershed

The results of the mean annual rainfall of the years 1998 to 2020 of the study watershed ranges from 1437.574 to 2062.856mm. The lowest average rainfall for the period from 1998 to 2020 (1437.574 mm) was recorded at Chida station while the highest (2062.85mm) was

recorded at Gessa station. According to (Mezga et al., 2014), this difference may be attributed due to the orographic effect arising from altitude difference. The level of rainfall distributions in the study watershed was categorized as very low (1479.24-1621.7mm), low (1621.71-1697.25mm), moderate (1697.26-1770.64mm), high (1770.65-1863.45mm) and very high (1863.46-2029.66mm).

Table 4-9: Meteorological stations and Mean Annual Rainfall of the Study Watershed

Meteorological station name	Recorded year	Station coordinate(X)	Station coordinate(Y)	Station elevation	Mean annual rainfall (mm)
Tarcha	1998-2020	297681	790592	1335	1513.9
Gessa Chare	1998-2020	310346	776774	2251	2062.856
Chida	1998-2020	255191	792764	1649	1437.574
Dedo	1998-2020	264587	831438	2210	1736.12

Table 4-10: Rainfall distribution and its rank as per suitable for groundwater availability

Classified Precipitation(mm)	Area coverage(sq.km)	Percentage (%)	Groundwater potentiality class
1863.46-2029.66	71.68	5.896	Very high potential
1770.65-1863.45	137.78	11.34	High potential
1697.26-1770.64	237.31	19.52	Moderately potential
1621.71-1697.25	413.86	34.04	Low potential
1479.24-1621.7	355.05	29.23	Very low potential

High rainfall is favorable for high groundwater potential formation (Adiat, 2012); hence during the weighting analysis 5 was assigned for very high controlling class, which is 1863.46-2029.66mm on the area of 71.68 km², 4 for high controlling class which is (1770.65-1863.45mm) area of 137.78 km², 3 for moderate controlling class which is moderate (1697.26-1770.64mm) area of 237.31 km², 2 for low controlling class which is low (1621.71-1697.25mm) area of 413.86 km², and 1 for very low controlling class which is (1479.24-1621.7mm) on the area of 355.05 km². Therefore, according to (Adiat, 2012) and (Stute *et al.*, 2007), the higher category recharges more precipitations to groundwater than the lower category.

Generally, the model output indicates that the higher rainfall identified from area marked by fully green and partly green in Figure 4:8 is also matched with point data measured by stations indicate filling of missing data by normal ratio method is more applicable to this study.

Because the maximum mean annual rainfall from the year 1998 to 2020 was recorded in this region.

It could be concluded that rainfall is ordered second highest controlling factor, with a weighting value of 16.6% and its scattered distribution in all region might create scattered groundwater distribution in this study. For more infiltrations to recharge study watershed, LULC class especially agricultural plantation and forest land should be conserved.

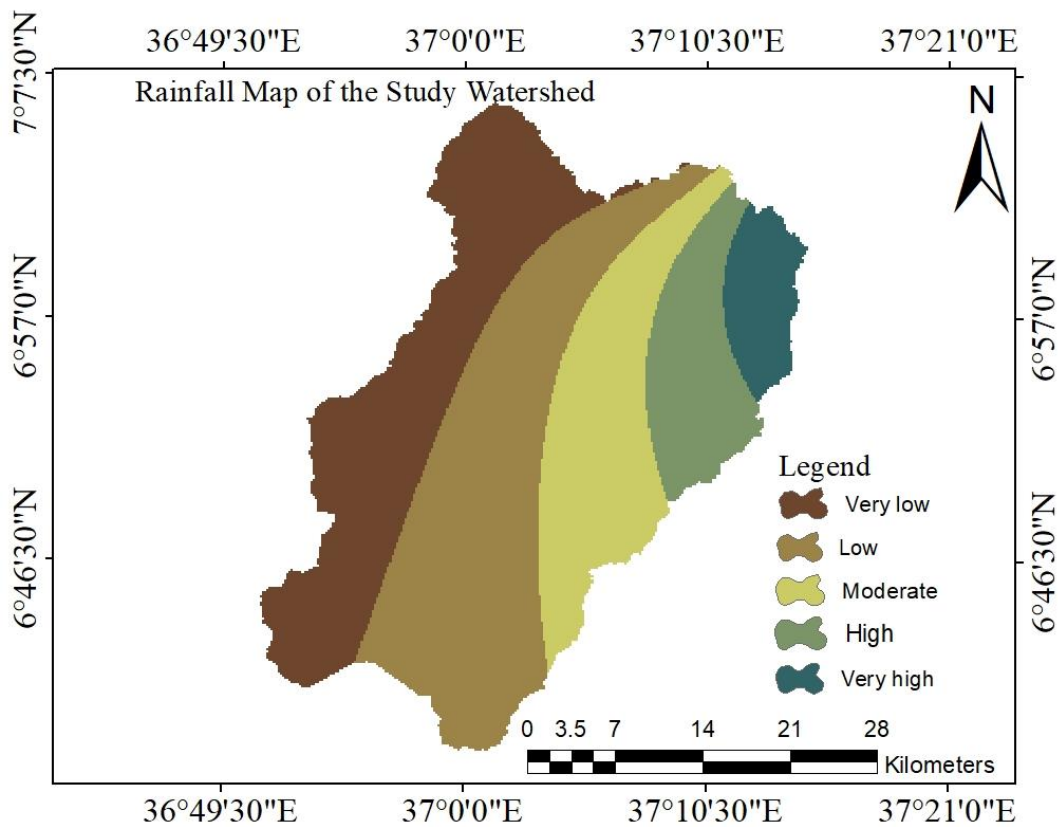


Figure 4-8: Reclassified Rainfall Map of the Study Watershed

4.1.9. Reclassified geology thematic layer of the study watershed

The geology of the study watershed is comprised of volcanic layers of basalts and trachyte's. The prepared geology thematic layer was used to identify different types of lithology units of the study watershed. The lithology of the study watershed is largely dominated by trachyte in Southern area, very few in North West and Central region of the study watershed whereas

basalt largely dominated in Northern and very few in south eastern portion of the study watershed.

The identified lithological units and their category values per its rank as per the suitable for groundwater potential formation were explained in (Table 4:11). The study conducted by (Kryštof , and Leta , 2000) show that distance from fault of trachyte is less than that of basalt. Other similar study conducted by (Seifu, 2012) verified that in case of groundwater bearing capacity, trachyte is characterized by deeply faulted structure than basalt is further indication of occurrence of groundwater. Therefore, the corresponding weight values of these geologic formations were arranged increasing order guided by (Kryštof , and Leta , 2000) : trachyte > basalt.

These geologic classes compared with study conducted by (Seifu, 2012) and (Kryštof , and Leta , 2000), and result of this geological comparison shows similarity with them interims of water bearing capacity. Moreover, most of faults delineated for lineament mapping from a southern region of this study watershed better verify trachyte form good aquifers system rather than basalt. Regarding this, a geological layer was developed to show areas of different geological character concerning groundwater potential formation in the study watershed.

In this study watershed, geology is the first factor among the selected significant variables evaluated to identify groundwater potential sites based on weighting value of 28% adopted to ascertain GWPZs of the study watershed.

Table 4-11: Lithology unity and its contribution rate to groundwater potential formation

Lithological units of the study watershed	Contribution to groundwater potential formation
Trachyte	Very high potential
Basalt	High potential

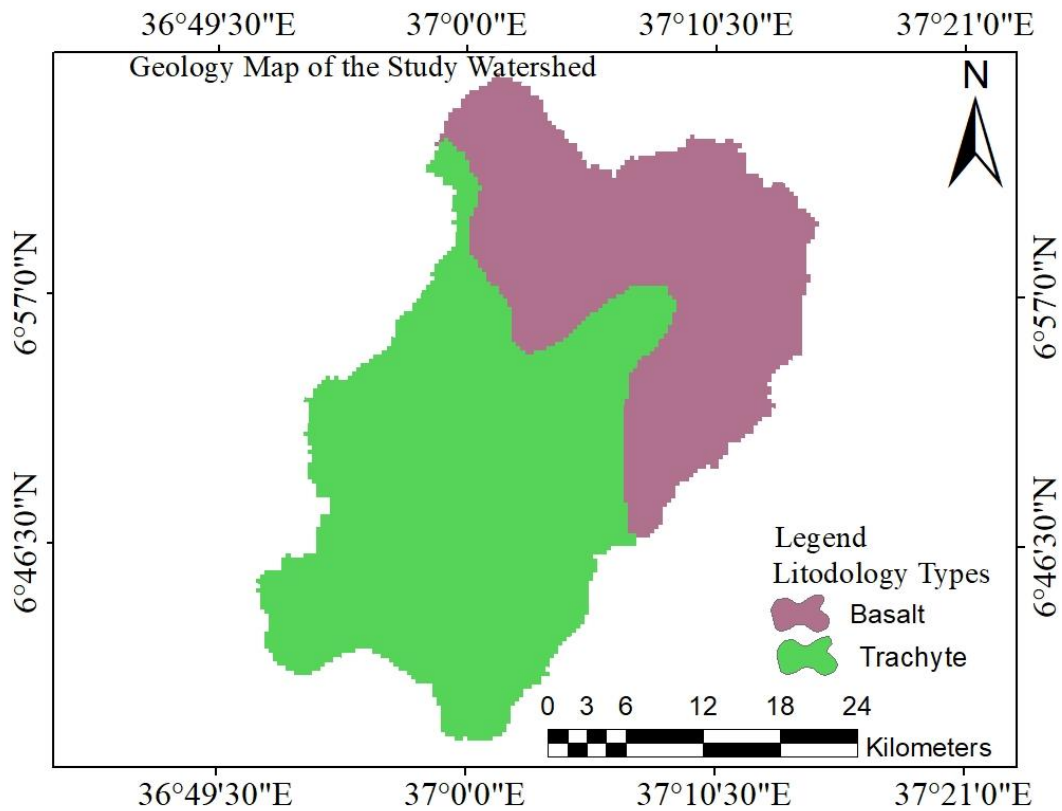


Figure 4-9: Reclassified Geology Map of the Study Watershed

4.1.10. Reclassified LULC thematic layer of the study watershed

The reason why this study used as a thematic layer is LULC classes play a varied role in terms of infiltration characteristics of the study watershed. A summary of results and the corresponding assigned values of each category in the study watershed were summarized in the (Table 4-12).

The study watershed consisted of five types of land uses and land cover classes as very high productive (forest land), high productive (cultivation land), moderate productive (wetland), low productive (shrub land), and very low productive (bare lands) potential for groundwater formation.

Agricultural plantations are first dominant LULC types which covers(48%)in this study watershed and were assigned a high rank because this classes are mostly associated with perennials crops such as inset, banana, coffee, mango, and others contribute high infiltration rate next to forest land underlying good groundwater potential sites. This is because the study

conducted by (Elias et al, 2019) shows that agroforestry region of the south-western highlands, were garden and forest coffee, enset, and mango are highly dominated. Therefore, current study watershed is found in this region was for further verified with LULC class studied by (Elias et al, 2019). This is the reason why agricultural plantations category categorized under high potential.

One of the second dominant land use/land cover categories in the study watershed is forest lands, which covers (44.06%) were assigned a very high rank because infiltrations contributed better than agricultural plantations. Moderate potential category is defined for wetland and low potentiality assigned for shrub land. Wetlands have moderate potential having more infiltration than runoff, but in this study case more of wetlands classes discharged from rivers.

The last categories, very low potential assigned for bare lands. This LULC types have very low water storing capacity and therefore were assigned low rank.

Therefore, contributions of forest lands and agricultural plantations classes play a great role in this study watershed from other LULC classes a better understanding of variations in the groundwater potential formation, and effects of groundwater changes in relation to infiltrations. In addition, most of the groundwater potential zones were identified from the regions of forest and agricultural plantations also show that they play a high role for future groundwater variation in this study watershed

Table 4-12: LULC types and its rank as per suitable for groundwater potential formation

Sub factor classes	Groundwater potential formation	Percentages coverage (%)
Forest land	High productive	44.06%
Agricultural plantations	Moderate productive	48%
Wetland	Moderate productive	2.007%
Shrub land	Low productive	5.832%
Bare lands	Very low productive	0.101%

Source: (Sewnet 2016)

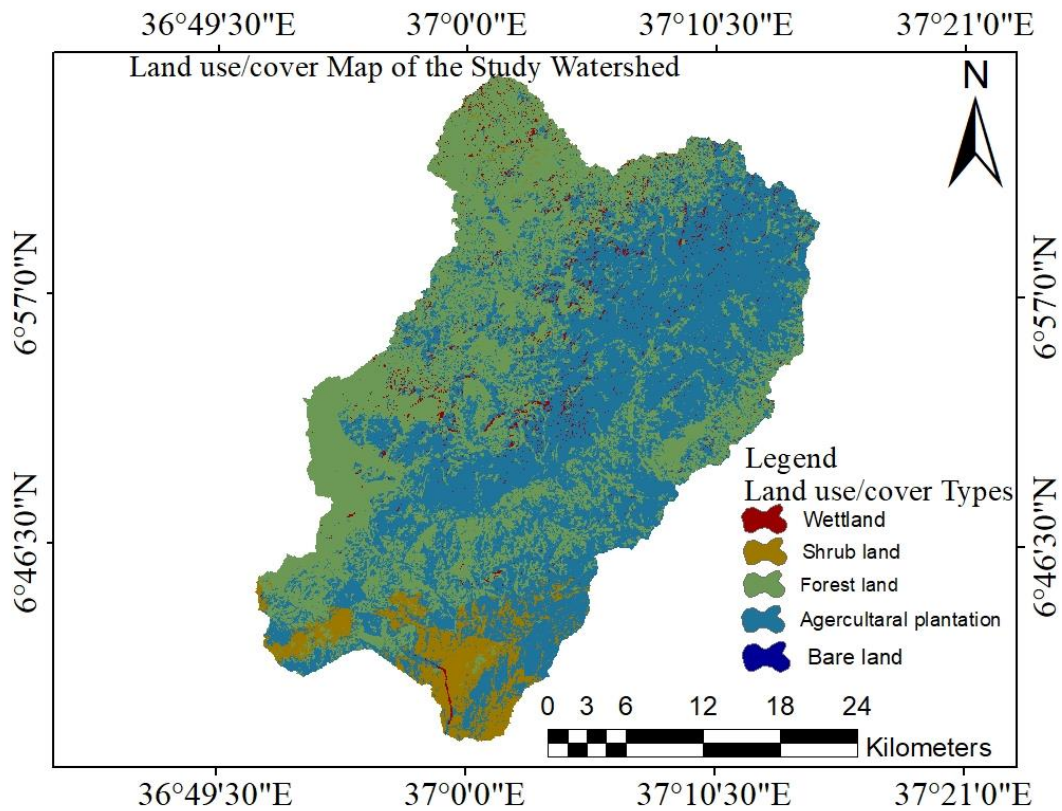


Figure 4-10: Reclassified LULC of the Study Watershed

4.2. Weight assessment using Analytical Hierarchy Process and overlay analysis

Groundwater distribution of the study watershed was governed by ten factors (geology, rainfall, lineament density, LULC, soil groups, elevation, distance to river, geomorphology, drainage density, and slope,) and they were set for overlay analysis in Arc GIS10.8_platform. Different controlling factors have no equivalent or the same importance during integration process therefore, various valued weights assigned to each factors to evaluate level of importance interims of groundwater potential formation. The summary of results showing relative weight, pairwise comparison matrices, Normalized pairwise comparison matrix, and Normalized Principal Eigen vector were obtained from AHP presented below in each separate table.

Table 4-13: Relative weight for identified thematic layers in study watershed

	Geo	Rf	Lulc	Soil	Lin	Gm	Slo	Ele	DD	Dr	Wt(%)
Geo	1.00	3.0	4.0	4.0	3.0	4.0	5.0	5.0	5.0	5.0	28
Rf	1/3	1.00	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0	16.6
Lulu	¼	1/3	1.000	1.0	0.7	2.0	3.0	3.0	3.0	3.0	9.5
Soi	¼	1/3	1.0	1.00	0.8	3.0	3.0	3.0	3.0	3.0	10.3
lin	1/3	½	1.429	1.25	1.00	3.0	5.0	4.0	3.0	3.0	12.9
Gm	¼	1/3	½	1/3	1/3	1.00	3.0	4.0	3.0	3.0	7.5
Slo	1/5	1/3	1/3	1/3	1/5	1/3	1.00	2.0	3.0	3.0	5.1
Ele	1/5	1/3	1/3	1/3	¼	¼	1/2	1.00	0.75	0.9	3.2
DD	1/5	1/3	1/3	1/3	1/3	1/3	1/3	1.333	1.00	0.85	3.4
Dr	1/5	1/3	1/3	1/3	1/3	1/3	1/3	1.111	1.176	1.00	3.5

Table 4-14: Pairwise comparison matrix

	Geo	Rf	Lulc	Soil	Lin	Gm	Slo	Ele	DD	Dr
Geo	1.0	3.0	4.0	4.0	3.0	4.0	5.0	5.0	5.0	5.0
Rf	0.333	1.0	3.0	3.0	2.0	3.0	3.0	3.0	3.0	3.0
Lulu	0.25	0.333	1.0	1.0	0.7	2.0	3.0	3.0	3.0	3.0
Soi	0.25	0.333	1.0	1.0	0.8	3.0	3.0	3.0	3.0	3.0
lin	0.333	0.5	1.429	1.25	1.0	3.0	5.0	4.0	3.0	3.0
Gm	0.25	0.333	0.5	0.333	0.333	1.0	3.0	4.0	3.0	3.0
Slo	0.2	0.333	0.333	0.333	0.2	0.333	1.0	2.0	3.0	3.0
Ele	0.2	0.333	0.333	0.333	0.25	0.25	0.5	1.0	0.75	0.9
DD	0.2	0.333	0.333	0.333	0.333	0.333	0.333	1.333	1.0	0.85
Dr	0.2	0.333	0.333	0.333	0.333	0.333	0.333	1.111	1.176	1.0
Sum	3.463	6.831	12.258	11.912	8.947	17.249	24.166	27.444	25.926	25.75

Where Geo= geology, RF = Rainfall, Slo = Slope, Gm = Geomorphology, Lin = Lineament density, DD= Drainage density, Soi= Soil group, Lulc = Land-use/land-cover, Dr=distance to river, Ele= Elevation

Table 4-15: Normalized pairwise comparison matrix

	Geo	Rf	Lulc	Soil	Lin	Gm	Slo	Ele	DD	Dr
Geo	0.288	0.439	0.3263	0.3358	0.335	0.2319	0.2069	0.1822	0.1928	0.1942
Rf	0.096	0.146	0.2447	0.2518	0.2235	0.1739	0.124	0.1093	0.1157	0.1165
Lulu	0.072	0.049	0.0816	0.0839	0.0782	0.1159	0.124	0.1093	0.1157	0.1165
Soi	0.072	0.049	0.0816	0.0839	0.0894	0.1739	0.124	0.1093	0.1157	0.1165

Lin	0.0962	0.073	0.1166	0.1049	0.1117	0.1739	0.2069	0.1457	0.1157	0.1165
Gm	0.072	0.073	0.0417	0.0279	0.0372	0.0579	0.124	0.1457	0.1157	0.1165
Slo	0.058	0.073	0.0272	0.0279	0.0223	0.0193	0.041	0.0728	0.1157	0.1165
Ele	0.058	0.073	0.0272	0.0279	0.0279	0.0145	0.0206	0.0364	0.0289	0.0349
DD	0.058	0.073	0.0272	0.0279	0.0372	0.0193	0.0138	0.0486	0.0386	0.033
Dr	0.058	0.073	0.0272	0.0279	0.0272	0.0193	0.0138	0.0404	0.0454	0.0388

Table 4-16: Normalized Principal Eigen Vector calculation

Selected parameters	Pairwise weight(Pw)	Percentage weight	NPEV=Pw*Wt
Geology	3.5	28	0.98
Rainfall	6.8	16.6	1.1
LULC	12.2	9.5	1.1
Soil group	11.9	10.3	1.2
Lineament density	8.95	12.9	1.15
Geomorphology	17.2	7.5	1.3
Slope	24.2	5.1	1.2
Elevation	27	3.2	0.86
Drainage density	25.93	3.4	0.88
Distance to river	25.75	3.5	0.9
Amax			10.67

The relative comparison can meet somehow the rule of AHP with computed consistence ratio 0.046 which was less than 0.1. Therefore, the pairwise comparison matrix computed in this analysis was acceptable and said to be consistent, because the matrix evaluated in this analysis was larger matrix

The percentage weights derived from AHP also show that all ten factors are important but the most influencing factors in the study watershed are (geology, rainfall, lineament, soil, and LULC). Based on reasons used for comparison to assign weights, geology was weighted first influencing factor. A lineament density was weighted third because it has linkage with geology regarding identified lithological units. In addition, a lineaments density is proportional to porosity and permeability creates opportunity of high potential. Soil group was weighted forth in the AHP because it controls infiltration rate depend up on permeability of soil characteristics. Rainfall was weighted second in the AHP because it is source for infiltrations. Elevation depends on nine factors under investigation, because study watershed has relatively lower topography in southern region rather than its distribution was not scattered

like other factors. Therefore, that it was evaluated relatively less than drainage density and distance to river, but lowest importance compared with first seven factors.

Ten thematic layers were reclassified on the basis of their respective significance in groundwater potential formation and their percentage weight derived by AHP were used to develop groundwater potential map within Mantha watershed was tabulated below.

Table 4-17: Groundwater controlling factors, their classes, rating values, and percentage weight with weighted overlay analysis

Factors	Factor classes	Factors potentiality	Factors rating	Percentage weight (%)
Distance to river	<213.8	Very high potential	5	3.5
	213.81-449.71	High potential	4	
	449.72-700.37	Moderate potential	3	
	700.38-995.26	Low potential	2	
Slope	995.27-1879.94	Very low potential	1	5.1
	0-5	Very high potential	5	
	5-10	High potential	4	
	10-20	Moderate potential	3	
	20-30	Low potential	2	
Elevation	>31	Very low potential	1	3.2
	600-1108.6	Very high potential	5	
	1108.7-1505.1	High potential	4	
	1505.2-1867.1	Moderate potential	3	
	1867.2-2186	Low potential	2	
Drainage density	2186.1-2798	Very low potential	1	3.4
	>3	Very low potential	1	
	2.25-3	low potential	2	
	1.5-2.25	Moderate potential	3	
	0.75-1.5	High potential	4	

	<0.75	Very high potential	5	
Lineament density	>0.662	Very high potential	5	12.9
	0.498- 0.662	High potential	4	
	0.352-0.498	Moderate potential	3	
	0.173-0.352	Low potential	2	
	0-0.173	Very low potential	1	
LULC	Forest land	Very high potential	5	9.5
	Cultivation land	High potential	4	
	Wetland	Moderate potential	3	
	Shrub land	Low potential	2	
	Bare land	Very low potential	1	
Soil groups	Dystric Fluvisols	Very high potential	5	10.3
	Dystric gleysols	Low potential	2	
	Dystric nitosols	Moderate potential	3	
	Eutric cambisols	High potential	4	
	Leptosols	low potential	2	
	Orthic acrisols	Moderate potential	3	
	Eutric nitosols	Moderate potential	3	
Rainfall	1479.24-1621.7	Very low potential	1	16.6
	1621`.71-1697.25	Low potential	2	
	1697.26-1770.64	Moderate potential	3	
	1770.65-1863.45	High potential	4	
	1863.46-2029.66	Very high potential	5	
Geomorphologic units	flat land	Very high potential	5	7.5
	Bottom/Plain land	High potential	4	
	Slope land	Moderate potential	3	
	Summit land	Low potential	2	

Geology	Basalt	Very high potential	5	28
	Trachyte	High potential	4	

4.3. Groundwater Potential Map of the Study Watershed

The groundwater potential map of the study watershed is presented in Figure 4:11. Very high groundwater potential zone developed through GIS and remote sensing is distributed within the central, northern region and very little in southern part of the study watershed which covers total area of 189.652km². This may be most of lineaments, and distance to river less than 600 meter were investigated from this region. Because aquifers close to river increase high recharge rates than those located far from river were distance to river less than 600m suggested by (Moghaddam et al, 2015) is more favorable for groundwater potential formation. In comparison, area with high, moderate and low groundwater potential distributions are scattered all over the study watershed which cover total area of 363.21, 426.855, and 235.82 km² respectively. This may be due to dual slope landforms characteristics of the study watershed made scattered distribution of groundwater zones in all regions. Within the study watershed, the highest area coverage was found in moderate groundwater potential. The spatial distributions of different groundwater potential zones derived from GIS, RS, and AHP predicted the study watershed patterns of groundwater potential controlling parameters. Spatially higher groundwater potential area distributed along area very close to river (bottom/plain landforms), lower distance to river, higher lineament distributions, lower topography, forest land and lower drainage patterns, some regions were also identified from agricultural plantations and wetland. Low groundwater potential zone was identified from the area of summit landform, higher elevation, and distance to river greater than 700m, and low lineament distribution region as shown the figure below. Most of dry wells are fallen in this low region also very better to see the region by displaying wells on above place where controlling variables classified to characterize groundwater potentiality.

Table 4-18: Area coverage of the study watershed groundwater potential zone

No	Groundwater potential zone	Area coverage (Km ²)
1	Very high	189.652
2	High	363.21
3	Moderate	426.855

4	Low	235.82
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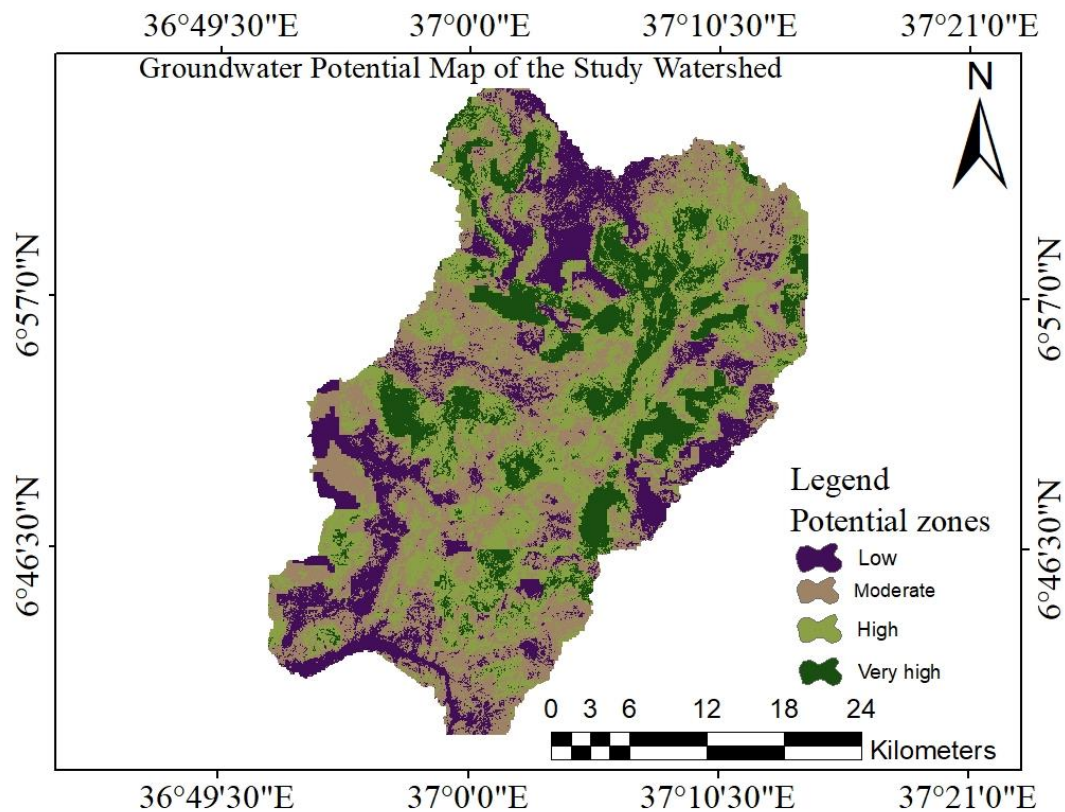


Figure 4-11: Groundwater Distribution Map of the Study Watershed

4.4. Validating Groundwater Potential Map using Well Data

The accuracy (Table 4-19) shows that the agreement made between wells and output potential map of the study watershed indicates that GIS and RS with AHP based investigation was accurate in 30 wells (85.714%) and not accurate in remaining 5 wells (14.286%). This means that 85.714% of groundwater potential mapping is directly related, and it shows effectiveness of GIS and RS method to save economy and time during groundwater development. 37 well data were displayed on the resultant groundwater potential map to examine for different categories groundwater potential zones with yield ranges. Most of collected well data have no well location point and other important information. Hence only 37 (appendix 2) available well data have recorded yield was used for result verification. Out of the 37 well yield data, 14 wells of the poor yield (from 0 to 60l/min) were fallen on the low groundwater potential zone (GWPZ) of the study watershed, and 12 wells were agreed (85.7%) with (GWPZ) and 2 wells

were not agreed. Two dry wells fallen on low potential zone were used to validate low potential zone. 10 wells with yields ranges from 60l/min to 180l/min agreed (83.33 %) were fallen on the moderate GWPZ with disagreed 2 wells greater than this ranges. 6 wells with yields ranges from 180l/min to 348l/min (90%)agreed and 1 well greater than this range fallen on high groundwater potential zone (GWPZ) . Whereas the rest 2 wells very high yield ranges 348l/min to 510l/min (100%) were fallen on the very high GWPZ. The only two wells were drilled from very high groundwater potential zone. This shows that most of the wells were drilled without baseline data. The other two dry wells were fallen on low groundwater potential zone better verify for this analysis especially for low region of produced GWPZ. As can be noted, some well in the low groundwater potential zone have a good yield due to the presence of these wells near river, even if the well identified from near mountain landform to better discussed in section 4.1.7. In addition, the same events happen also in moderate class with similar reason. Based on this verification, it can be concluded that the groundwater potential zones mapped by GIS and AHP methods are reliable according to validation done with helping of well data.

Table 4-19: Accuracy between the well and the identified GWPZ

Classified GWPZ	Recorded yield(l/min)	Number of recorded wells	Number of wells fall under classification	Accuracy (%)
Low	< 60	14	12	85.7
Moderate	60 to 180	12	10	83.33
High	180 to 348	7	6	90
Very high	>348	2	2	100

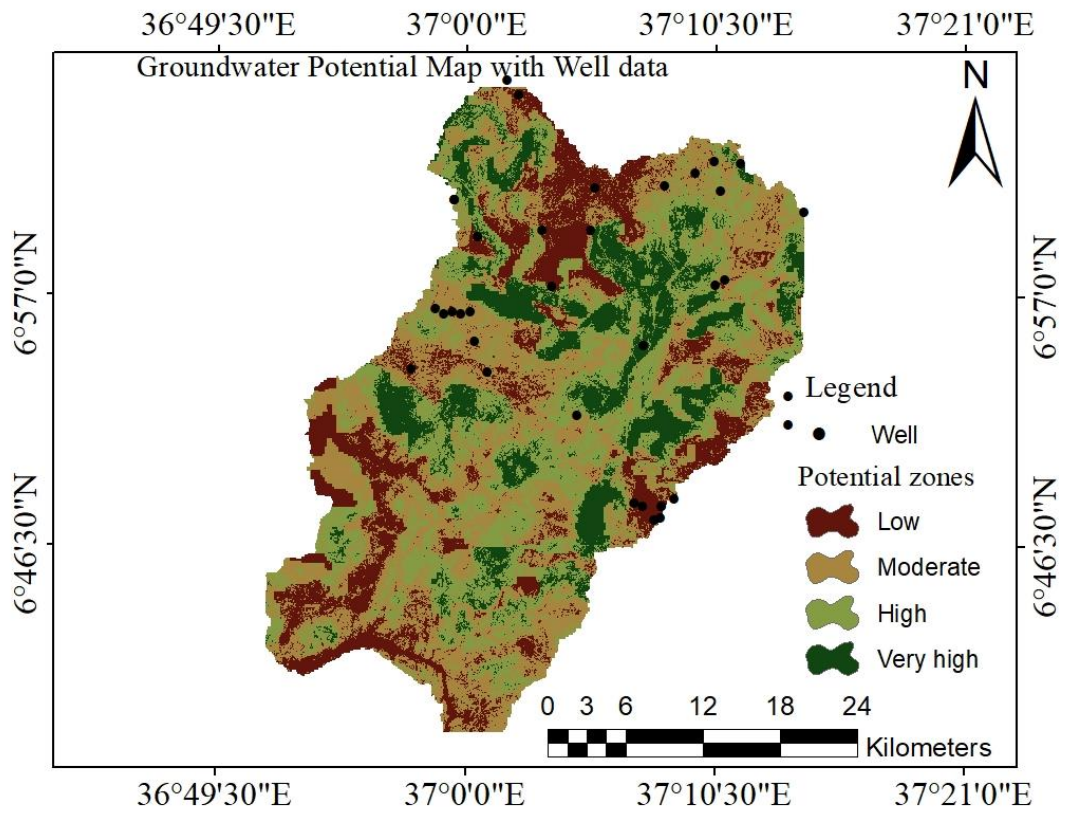


Figure 4-12: Groundwater potential map with well data

5. SUMMARY AND CONCLUSION

5.1. Summary

Most of groundwater potential studies conducted in Ethiopia were field survey based rather than GIS and remote sensing, which is not time and cost effective (Tesfaye, 2012). Therefore, GIS and remote sensing techniques are cost and time effective for mapping groundwater potential zone. In the current study Watershed, the number of population increases from year to year and they use potable drinking water and irrigation from Mantha Watershed. There is no previous study reported on current study Watershed regarding groundwater potential assessment. Hence, this study mapped the distributions of groundwater potential zones for the Mantha Watershed by applying GIS and remote sensing techniques with AHP to map groundwater potential zone with objective of groundwater potential assessment using various data sources.

In this study watershed, thematic maps of the distance to river, elevation, drainage density, lineaments density, and slope were developed from STRM DEM30m*30m spatial resolution using GIS10.8_platform. Rainfall data obtained from National Meteorology Agency was converted into areal rainfall using IDW interpolation techniques to map rainfall layer of the study watershed. Landsat 8 (OLI) for the year 2020 was used to classify LULC classes (forestland, agricultural plantation, wetlands, shrub lands, and bare lands) and mapping of land use/land cover layer of the study watershed using supervised image classification with maximum likelihood algorithm in ERDAS 2015 _platform. The remaining three thematic layers (soil, geomorphology, and geology) were developed from the existing soil, geology, and geomorphology map of Ethiopia using the geo-processing clip toolbox in Arc-GIS 10.8_platform by applying study watershed shape file boundary. Ten controlling factors (geology, rainfall, LULC, elevation, geomorphology, lineament density, LULC, soil, drainage density, distance to river and slope) were reclassified on the basis of their respective significance in groundwater potential formation , and finally, merging them to develop groundwater potential map using weights derived by AHP technique with overlay analysis.. The spatial distribution of groundwater potential sites in the study watershed was explored by determining the distribution of selected factors that are responsible for groundwater occurrence.

The spatial distribution of the groundwater potential zones, in the study watershed were assessed and mainly controlled by geology, rainfall, lineament, soil, and LULC. The integration of the ten thematic layers result showed that of the watershed have very high groundwater potential zones mapped in the central, northern region and very little in southern part of the study watershed which covers total area of 189.652km². However, area with high, moderate and low groundwater potential distributions are scattered all over the study watershed which cover total area of 363.21, 426.855, and 235.82km² respectively. Within the study area watershed, the highest area coverage was found in moderate groundwater potential

The acceptable results were done by comparing the well data with the groundwater potential zone map of the study watershed. Zones where well yield lie less than 60 l/min were classified as low, 60 l/min to 180l/min as moderate, lie between 180 l/min to 180 to 348 l/min as high and more than 348 l/min were classified as very high potential groundwater regions of the Mantha watershed

Therefore, based on the study finding revealed in this study watershed, and to get further more groundwater potential zones, the following basic recommendations have been pointed out.

- ✚ To more evaluate hydrogeological investigation for Mantha watershed, field geophysical studies, and other models coupled with GIS and RS based geological surveying should be required for further studies. Because integrated approaches are basis for safe designing to provide best optimal groundwater exploration well location.
- ✚ The significant correlation between output map of this study watershed and the well data prove to demarcate the possible potential zones. Therefore, this study proposes groundwater should be drilled on nearly or inside any parts of the study watershed marked by partly green color or fully green color (Figure 4:12).
- ✚ Groundwater potential map investigated in this study may be used as baseline data for groundwater development and management of the resource specially factors associated with LULC. Therefore, higher institutions, research centers, and non-governmental organization should undertake rehabilitation of Mantha watershed to get further more groundwater potential zones.

- ✚ The geologic structures in the study watershed should be study deeply with field based investigation because the occurrence of groundwater potential formation is determined with geologic structures. Therefore, the occurrence of groundwater is better contributed if this recommendation will be applied.
- ✚ Detailed investigations by adding other controlling factors and good groundwater drilling systems and accurate pumping methodology are thus necessary for a full understanding of groundwater potential patterns in study watershed especially in southern region.
- ✚ It is recommended to investigate and estimate groundwater recharge, and hydrological studies in the study watershed as important parameters for groundwater development and groundwater management.

5.2. Conclusions

The ultimate purpose of this study was to assess groundwater potential assessment in Mantha watershed using geographic information system (GIS) and remote sensing (RS). In context of this study results, and finding of the integration of GIS and remote sensing with AHP approaches demonstrated as time and cost effective tool to identify groundwater potential zones in this study watershed. So that this study accomplished objectives set out in this study watershed,

- 🌐 Groundwater potential zones were demarcated using an integrated approach with AHP based analysis.
- 🌐 The study watershed was characterized by mapping ten thematic layers of geology, rainfall, geomorphology, LULC, soil, lineament density, drainage density, and distance to river, elevation, and slope from various data sources to predict the study watershed patterns of groundwater potential controlling parameters.
- 🌐 The groundwater potentiality of the study watershed could have been validated by drilled well data within each groundwater potential zone category. Therefore, the result obtained from the models is acceptable compared with well data, and the result correlated 85.714%.

5.3.Recommendations

This study finding has pointed out in section 5.1 and also concluded in section 5.2. Therefore, based on this the following recommendations have been addressed for future groundwater development nearly or inside of the study Watershed.

- 🌿 Groundwater should be drilled from any region of high or very high potential zones have been confirmed in this study Watershed especially from undrilled Southern region.
- 🌿 Groundwater potential map produced using GIS and remote sensing in this study Watershed should be used as baseline data for next groundwater researchers and drillers.
- 🌿 The hydrogeological features should be study deeply.
- 🌿 Field geophysical based study should be conducted for further verification.
- 🌿 Hydrological study should be investigated to fully characterize groundwater hydrology of the Mantha Watershed.

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APPENDICES

Appendix 1 : The ground truth GPS points collected from the actual LULC types during field observation

LULC class	X coordinate	Y coordinate	X coordinate	Y coordinate
Forest land	280438	764839	282179	773065
	268921	752984	288219	781062
	294987	756905	293206	776668
	278232	765396	296257	775722
	283872	765088	296663	758019
	282256	768487	294998	756765
	280397	764943	297852	759007
	283099	764740	299094	747240
	283872	765144	268276	749057
	283071	764782	268747	747926
	283948	765085	269341	753278
	286962	769863	276002	760112
	282365	768315	278364	781345
	296689	758065	279042	747270
	284675	779290	279744	766157
	278546	745150	281752	744888
	282147	746264	281741	744755
	273210	741726	264176	744339
	279121	747136	279628	746205
278497	745622	-	-	
Agricultural plantation	283187	755768	295843	760332
	278493	752897	295768	760074
	297209	759554	290399	761556
	290053	760211	298280	765248
	296458	763204	278544	770486
	303973	776403	304248	775178
	305223	772192	300334	775884
	301522	773743	271238	757261
	264497	741405	264956	744431
	287580	766340	287235	775221
	284875	781421	270499	746106
	270687	746343	276221	746329
	276409	746302	275975	747035
	283183	784221	287926	771724
	286988	773415	-	-
Bare land	263930	741112	264687	740006
	263929	743437	273035	740501

	263424	744092	284856	738797
	289183	747908	289168	747688
	292645	749837	300967	757908
	302688	760586	302285	760562
	305256	764769	305408	768880
	305037	775246	299950	780658
	278200	774248	278618	774082
	275865	768941	-	-
Wetland	291486	772082	293023	776323
	298542	769418	284886	771731
	298830	779457	297857	779947
	283672	760236	275893	769168
	277126	739859	299834	757352
Shrub land	278454	740565	269447	743430
	263131	746577	263599	742178
	264529	741457	276259	739521
	281727	735195	286201	746030
	287868	742886	284676	745077
	275520	745437	282347	780084
	280344	778366	-	-

Appendix 2: Observation well data used for validation and their yield category

No	Wells	y	x	Depth(m)	Yield(min/l)	Class
1	Well-1	762998	274794	72.4	0	Low potential
2	Well-2	751330	293641	81	0	Low potential
3	Well-3	752344	294165	41.8	0	Low potential
4	Well-4	751517	294072	80.9	0	Low potential
5	Well-5	773731	288706	80	13.5	Low potential
6	Well-6	765146	279634	67.8	0	Low potential
7	Well-7	762785	280630	80.7	0	Low potential
8	Well-8	773274	279945	80	0	Low potential
9	Well-9	777007	289040	150m	360	Low potential
10	Well-10	767307	277307	50	60	Low potential
11	Well-11	769452	285686	64	120	Low potential
12	Well-12	785366	282217	64	57	Low potential
13	Well-13	752358	292693	65.7	60	Low potential
14	Well-14	767307	278582	50.2	54	Low potential
15	Well-15	767680	276660	41.4	180	Moderate potential
16	Well-16	778177	296809	58.8	156	Moderate potential
17	Well-17	752928	295139	79.5	78	Moderate potential
18	Well-18	773769	284929	55.1	78	Moderate potential
19	Well-19	767498	277953	46.2	66	Moderate potential

20	Well-20	777232	294410	55.5	78	Moderate potential
21	Well-21	767425	279379	47.2	72	Moderate potential
22	Well-22	758712	304015	58.8	156	Moderate potential
23	Well-23	760882	303990	68.5	120	Moderate potential
24	Well-24	752663	292020	62.8	150	Moderate potential
25	Well-25	779122	298289	150	330	Moderate potential
26	Well-26	769914	299084	150	240	Moderate potential
27	Well-27	776136	278100	64	180	High potential
28	Well-28	769491	298379	200	300	High potential
29	Well-29	759440	287595	150	282	High potential
30	Well-30	776136	278100	82	270	High potential
31	Well-31	776815	298744	42.2	348	High potential
32	Well-32	776136	278100	43.6	180	High potential
33	Well-33	775121	305280	150	316.2	High potential
34	Well-34	764854	292770	150	510	Very high potential
35	Well-35	778959	300325	200	420	Very high potential
36	Well-36	751330	293640	80.9	Dry	Low potential
37	Well-37	752345	294164	42.1	Dry	Low potential

Appendix 3: Annual rainfall distribution of study watershed

No	Station name	Recorded year	X	y	Annual rainfall
1	Tarcha	1998	297681	790592	1555.1
2	Tarcha	1999	297681	790592	1405.8
3	Tarcha	2000	297681	790592	1116.3
4	Tarcha	2001	297681	790592	1526.5
5	Tarcha	2002	297681	790592	1655.2
6	Tarcha	2003	297681	790592	1412.1
7	Tarcha	2004	297681	790592	1505.5
8	Tarcha	2005	297681	790592	1493.7
9	Tarcha	2006	297681	790592	1593.5
10	Tarcha	2007	297681	790592	1961.5
11	Tarcha	2008	297681	790592	1593.3
12	Tarcha	2009	297681	790592	1369.2
13	Tarcha	2010	297681	790592	1561.6
14	Tarcha	2011	297681	790592	1368.5
15	Tarcha	2012	297681	790592	1151.3
16	Tarcha	2013	297681	790592	1877.3
17	Tarcha	2014	297681	790592	1406.3
18	Tarcha	2015	297681	790592	1564.1
19	Tarcha	2016	297681	790592	1330.2
20	Tarcha	2017	297681	790592	1599

21	Tarcha	2018	297681	790592	1565.3
22	Tarcha	2019	297681	790592	1430.7
23	Tarcha	2020	297681	790592	1877.7
24	Chare	1998	310346	776774	1798.6
25	Chare	1999	310346	776774	1900.8
26	Chare	2000	310346	776774	1516.8
27	Chare	2001	310346	776774	1950.6
28	Chare	2002	310346	776774	1665
29	Chare	2003	310346	776774	1671.9
30	Chare	2004	310346	776774	1691.8
31	Chare	2005	310346	776774	1373.2
34	Chare	2006	310346	776774	1355.4
35	Chare	2007	310346	776774	2570.5
36	Chare	2008	310346	776774	1965.5
37	Chare	2009	310346	776774	1539.4
38	Chare	2010	310346	776774	1645.7
39	Chare	2011	310346	776774	2204.5
40	Chare	2012	310346	776774	1513.6
41	Chare	2013	310346	776774	1800.3
42	Chare	2014	310346	776774	2618.1
43	Chare	2015	310346	776774	2233.5
44	Chare	2016	310346	776774	2015.2
45	Chare	2017	310346	776774	2251.6
46	Chare	2018	310346	776774	3451
47	Chare	2019	310346	776774	3086.1
48	Chare	2020	310346	776774	3626.6
49	Chida	1998	255191	792764	863.9
50	Chida	1999	255191	792764	1118.5
51	Chida	2000	255191	792764	1188.5
52	Chida	2001	255191	792764	1695.5
53	Chida	2002	255191	792764	1407.75
54	Chida	2003	255191	792764	1452
55	Chida	2004	255191	792764	1125.3
56	Chida	2005	255191	792764	1819.23
57	Chida	2006	255191	792764	1716.4
58	Chida	2007	255191	792764	1490
59	Chida	2008	255191	792764	1301.698
60	Chida	2009	255191	792764	1048.589
61	Chida	2010	255191	792764	1756.089
62	Chida	2011	255191	792764	1342

63	Chida	2012	255191	792764	1045.1
64	Chida	2013	255191	792764	1656.7266
65	Chida	2014	255191	792764	1560.7
66	Chida	2015	255191	792764	1080.3
67	Chida	2016	255191	792764	1329.326
68	Chida	2017	255191	792764	1514.4
69	Chida	2018	255191	792764	1317.61
70	Chida	2019	255191	792764	2365.3
71	Chida	2020	255191	792764	1869.5
72	Dedo	1998	264587	831438	1956.7
73	Dedo	1999	264587	831438	1825.4
74	Dedo	2000	264587	831438	1376.7
75	Dedo	2001	264587	831438	1457.9
76	Dedo	2002	264587	831438	1398.1
77	Dedo	2003	264587	831438	1058.5
78	Dedo	2004	264587	831438	1141.6
79	Dedo	2005	264587	831438	1366.6
80	Dedo	2006	264587	831438	2334.2
81	Dedo	2007	264587	831438	2173.634
82	Dedo	2008	264587	831438	1826.945
83	Dedo	2009	264587	831438	1788.34
84	Dedo	2010	264587	831438	2235.4
85	Dedo	2011	264587	831438	1426.32
86	Dedo	2012	264587	831438	1714.2
87	Dedo	2013	264587	831438	2466.9
88	Dedo	2014	264587	831438	2718.21
89	Dedo	2015	264587	831438	1272.8
90	Dedo	2016	264587	831438	1785.76
91	Dedo	2017	264587	831438	1522.2
92	Dedo	2018	264587	831438	1331.65
93	Dedo	2019	264587	831438	1709.4
94	Dedo	2020	264587	831438	2041

Appendix 1: Wells close to watershed producing high yield

